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Comparing the ability of subjective quality factor and information theory to predict image quality

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Comparing the ability of Subjective Quality Factor and Information Theory to predict Image quality.

By

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" Comparing the ability of Subjective Quality Factor and Information Theory to predict Image Quality."

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Shyi-Shyang Li

Submitted to the Center for Imaging Science
in partial fulfillment of the requirements
for the Master of Science Degree at the
Rochester Institute of Technology

ABSTRACT

The purpose of this project is to compare the ability of the Subjective Quality Factor and Information Theory to predict image quality as a function of film speed for two different methods of exposing film. One exposure holds the total number of photons constant and the other allows the flux to vary.

This study will:

1. Determine the relationship between grain size and image quality for constant flux when the resulting images are reproduced at the same size.
2. Compare the resulting granularity and image quality of the constant flux condition with the normal exposure method of varying the shutter speed as a function of film speed.
3. Compare the ability of Subject Quality Factor and Information Theory to accurately predict resulting image quality.

ACKNOWLEDGMENTS

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First, to Dr. Edward M. Granger who provided the ongoing technical insight and guidance that allowed me to proceed through the difficult periods. Dr. Granger served as the principal advisor. I must also thank Mr. Joseph Altman for serving on my thesis committee member as well as providing technical support.

Special thanks are extended to Dr. Dana G. Marsh for the continuing support and encouragement through the highs and lows that went with this project. Thanks for being understanding.

A special word of thanks is owed to my loving wife, Liang-Jen. Thoughout the long period of this project she stood steadfastly by me. The many hours and days she willingly gave for me to complete this project. Her unwavering patience made this struggle an enjoyable journey and I will forever be indebted.

Finally, I like to present this work to my parent, they provided financial and emotional support made the completion of this work possible.

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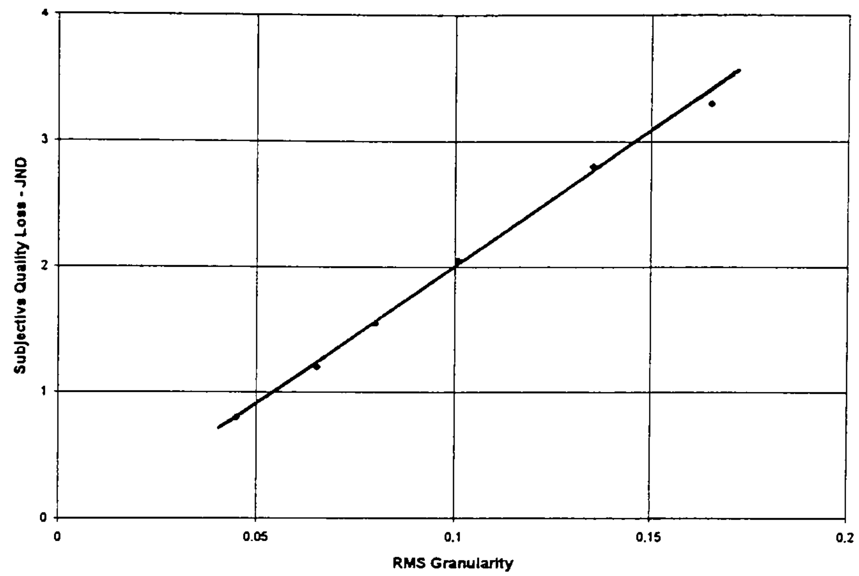
I. INTRODUCTION

1. Granularity and Image Quality

When an emulsion is uniformly illuminated and then developed, the negative shows density fluctuations due to the random distribution of developed silver particles in the emulsion. This is known as photographic granularity. The effect is to introduce a small, unpredictable uncertainty into the photographic blackening in each small area of the negative. This uncertainty is of great importance in imaging science, because it sets a limit to the quality of photographic images. Although the individual density fluctuations are unpredictable, their mean magnitude (root mean square density fluctuation) is a well defined statistical characteristic of the grain distribution in a uniformly exposed negative, and determines the photographic noise-level. Granularity is a measure of the random density distribution created by photographic grain in the image, and depends on the size and distribution of the grains in the developed photosensitive material. It is measured by scanning, with a microdensitometer, areas of the photosensitive material that have been exposed and developed to a uniform density. The granularity measured is a function of the circular aperture used in the microdensitometer, the density distribution of the developed photographic emulsion, and the type of emulsion [*Wisner*,1986].

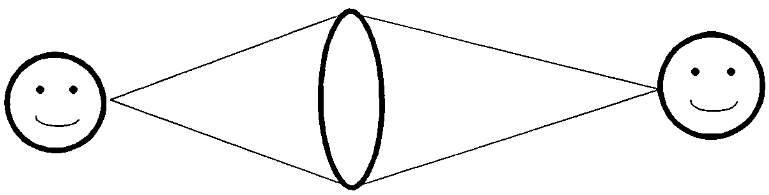
It is obvious that image quality will be degraded as the grain noise increases. In a recent study[*Lisson*,1983], the loss in image quality was found to be linear with respect to the variance of the noise (rms granularity), expressed in density units and shown in Figure(1).

Figure 1 Subjective Quality Loss vs. Granularity



In this project, some of the film samples will be exposed under constant photon flux in the optical system. This means that in a given amount of time, N photons will pass through a constant diameter lens pupil from a given area on the original object. As a result of this restriction for a constant shutter speed, the lens focal length and the image size increase in direct proportion to the film speed. Since the final prints made from different films with different speeds will be printed to the same size, the system MTF and granularity will be scaled by the magnification required to obtain equal print size.

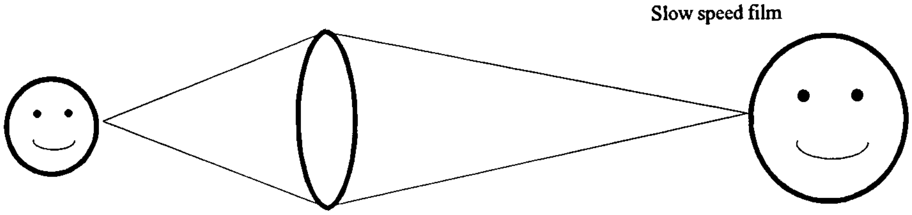
The following diagram provides information about the relationship of the object lens to the different size images that result due to film speed.



25 mm lens

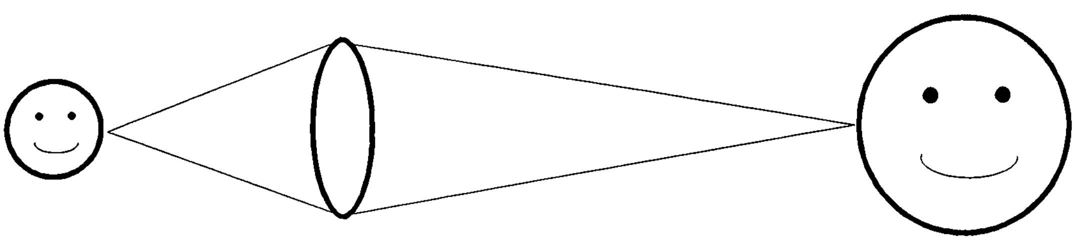
$F^{\#}$: 4

Slow speed film



50 mm lens

$F^{\#}$: 8



135 mm lens

$F^{\#}$: 22

Fast speed film

As shown in the diagram, with the constant flux condition, the faster the film, the bigger the image generated. The negative must be magnified to make the slower film generate the same size print as the fast film.

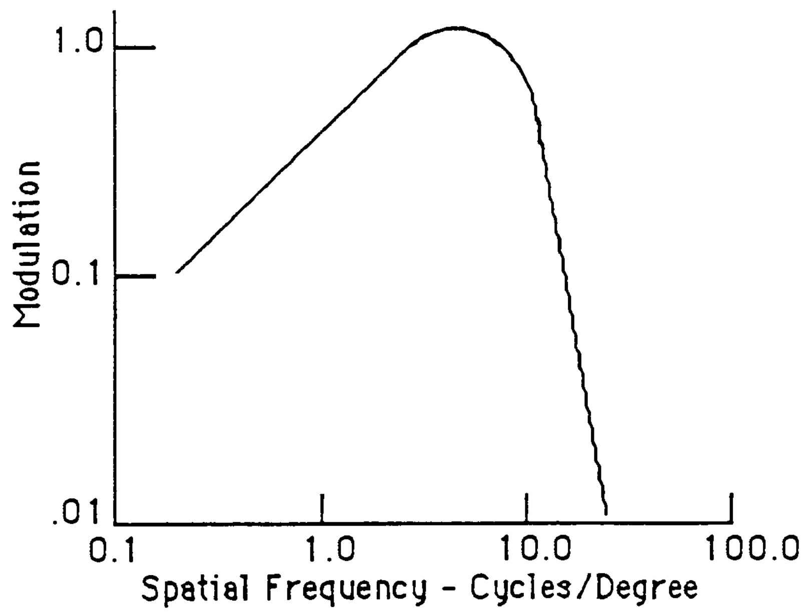
2. Subjective Quality Factor (SQF)

A perceptible difference in image quality can be obtained by changing SQF by 7-10%. This phenomenon of just noticeable difference (JND) being related to a constant percentage change in the stimulus has been observed for many neural processes. Tasks such as judging weight and loudness of sounds follow what is known as Weber's Law. This led Granger [*Granger*,1972] to hypothesize that image quality might in some way be related to a logarithmic spatial frequency weighting of the system Optical Transfer Function (OTF). If so, image quality might correlate with the area under the system OTF on a log spatial frequency scale.

The Subjective Quality Factor (SQF) was developed by Granger and Cupery, as the result of a search for an objective figure of merit which could be easily calculated and directly measured in practice and which would correlate with subjective rank regardless of Modulation Transfer Function (MTF) form. A number of experiments were performed to test the quality factor for a wide variety of MTF shapes. The results of the experimental program were that SQF was able to predict image quality within normal reader error and was 0.988 correlated with the measured data [*Lisson*,1983].

The quality of a visual image is related to the scale of the image on the retina. The human visual system has an MTF which peaks in the region of 10-20 cycles/mm at the retina. A typical visual system MTF is shown plotted Vs log frequency in Figure 2.

Figure 2. A typical visual system MTF



By postulating an arbitrary bandpass nature for the eye, the limits of integration to stimulate this effect have been defined.

Based on these observations, a one-dimensional SQF was defined as the integral of the system MTF(including lenses and films) between the limits of 10-40 cycles/mm when the MTF has been scaled to the retina of the observer by the magnification of the system, which includes the eye.

$$SQF = k\int_{10}^{40} \left|\tau(f)\right| \partial(\log f) \qquad (1)$$

$\tau(f)$ is the Optical Transfer Function.

f is the spatial frequency.

$1/k$ is a normalizing constant obtained by equating the above integration to =1.

There is no reason to limit the considerations to one-dimensional MTF descriptions. Because real images involve a two-dimensional MTF, a two dimensional MTF must be factored into the system. That is, the impression of quality is obtained by equally weighting information over all directions. The SQF value can be obtained for a general MTF by describing the system MTF in polar coordinates and performing the following integration:

$$SQF = k\int_{10}^{40}\int_{0}^{2\pi} \left|\tau(f,\theta)\right| \partial(\log f)\partial\theta \qquad (2)$$

Where: f is the spatial frequency in cycles / mm along a given azimuth θ of line structure.

k is the appropriate normalizing constant.

$$k = \int_{10}^{40}\int_{0}^{2\pi} \partial(\log f)\partial\theta \qquad (3)$$

The above formula allows a simple calculation of the quality of a print which lies within the limits of the Image Sharpness Scale (ISS) [*Granger*,1972] quality range.

It is characteristic of the SQF system and of subjective evaluation, that a quality assessment is not intrinsic to the image itself but only to the image as viewed at a specified magnification. Therefore, it is important that the proper system magnification be specified when calculating the SQF of a system.

3 Information Theory

3-1 General Information

The theorems within the general field of information theory are based on research by Shannon in 1948. These theorems were developed largely within the context of electrical communication channels but they may be readily adapted to any other type of communication system, such as the optical transmission or photographic recording of information.

It is estimated that the total amount of printed information alone is in excess of 10^{16} bits per year and that this figure doubles about each decade. In view of these present and future large-scale information-handling problems, the need for a fundamental analytical approach as provided by information theory is self-evident.

In photographic applications the photographic process is used as the recording medium and it is important to achieve the highest information recording rate. The statistical structure of the incoming signal is fairly well known, and the question becomes one of how to best present the signal to the photographic recording element. As a result, it may be desirable to match the Wiener spectrum of incoming signals to the spatial frequencies in the photographic recording element which yield the highest information capacity and rate. These frequencies are determined by the system MTF and the Wiener spectrum of the system noise. This approach demonstrates the very close relationship between information capacity, recording rate, and DQE $\left[Da\,\mathrm{int}\,y\&\,Shaw,1974\right]$.

3-2 Photographic application : Discrete Signal

When a specified type of signal (for example, in binary form) is to be stored photographically with the highest information storage per unit area, simplified models of the photographic process as a storage medium may prove adequate. Altman and Zweig gave a method of analysis based on a unit storage cell in the image using a simple model for the influence of noise according to Levi $\left[Levi,1958\right]$. The information capacity per unit area can be written in the form :

$$C = N \log_2 M \qquad (4)$$

$$M = \frac{RA^{\frac{1}{2}}}{2\,KG^{\frac{1}{2}}} + 1 \qquad (5)$$

where: c is a constant.

C is the information capacity of the channel

M is the number of recording levels

N is the number of cells

R is the density range (D_{min} $-$ D_{max})

A is the cell size.

$N = A^{-1}$

The parameter R may be assumed to be constant for a given photographic process and so for a specified separation criterion, K, only A remains as a variable and equation (5) can be written as equation (6):

$$C = \left(\frac{1}{A}\right)\log_2\left(cA^{\frac{1}{2}} + 1\right) \quad (6)$$

Investigation of equation (6) reveals that C increases as A decreases, so A should be as small as possible for maximum information capacity. However, at least two recording levels are necessary, so we conclude that, in principle, binary recording will give optimum information capacity. This conclusion is confirmed by the results of Altman and Zweig for a series of Kodak films which are summarized in Table I.

TABLE I

	Spread function diameter μm	Available levels M	$\log_2^M$	Bit capacity for an image area of 0 × 10 μm M-level	Binary	Experimental
Kodak Fine Grain Cine Positive	-----	8	3	0.33	0.11	-----
Recordak Fine Grain Type 5454	12.5	6	2.6	1.6	0.64	1.1
Recordak Fine Grain Type 7456	15	4	2	0.88	0.44	1.1
Kodak plus-X	-----	3	1.6	0.33	0.21	-----
Kodak Pan-X	15	3	1.6	0.7	0.44	0.5
Kodak Royal-X Pan	27	2	1	0.14	0.14	0.05
Kodak High Resolution Type 649	1	2	1	160	160	160

An analysis of binary and multilevel recording by Altman and Zweig [*Altman& Zweig*,1963] concludes that the gain in information capacity by using multilevel rather than binary recording is not substantial. It follows from equation (4) that an increase in M gives only a logarithmic increase in capacity, and therefore small cell size is the most important factor. The cell size or spread function having a storage area of $1\,\mu m \times 1\,\mu m$, as opposed to $100\mu m \times 100\mu m$, would give an increase in capacity of 10^4 Where binary messages and codes are commonplace, recording levels higher than two may involve coding complications and difficulties, especially in view of the fact that the levels have to be well separated. For all these reasons multilevel recording may offer little practical advantage over binary.

3-3 Photographic Application: Continuous Signal

It is important to know that the results obtained for information capacity when using a continuous approach will not be the same as using of the discrete approach, but in practice they may turn out to be quite close. The results are different because they concern different questions, or types of information input. The great benefit of this approach is that it allows the information capacity to be expressed as a function of spatial frequency, and in turn the close relationship between information transfer rate and DQE then become apparent. For applications in scientific photography where overall systems, including the photographic recording element, must be designed to achieve the highest information rate for an incoming signal, this spatial frequency approach is usually taken as the result for the continuous channel with average mean-square limitation and Gaussian noise. In fact the photographic process is more nearly a peak-limited channel, with its operating region between fog density and Dmax. A difficulty arises due to the non-linearity of the photographic process and the wide variation of its imaging properties over the range of its operating limits.

According to Dainty $\left[Da\text{int}\,y\&Shaw,1974\right]$ the result for the information capacity of a continuous channel with an average "power" limitation is :

$$C = \Delta f \log_2 \frac{P + N}{N} \qquad (7)$$

If the signal and noise power are approximately constant over two adjacent regions A and B, each of width 1/2 f, then the capacity for the total band width approximates to :

$$C = \tfrac{1}{2}\Delta f\left(\log_2\left(1 + {}^{P_A}\!/_{N_A}\right) + \log_2\left(1 + {}^{P_B}\!/_{N_B}\right)\right) \qquad (8)$$

If we use the power spectrum of the signal, $W_N(f)$ for P and the power spectrum of the noise $W_N(f)$ for N, then

$$\int_0^\infty \log_2\left(1 + \frac{W_S(f)}{W_N(f)}\right)\partial\theta \qquad (9)$$

Since signal and noise are two dimensional functions of space, for photographic images

$$C = \tfrac{1}{2}\int_{-\infty}^{+\infty}\int_{-\infty}^{+\infty}\log_2\left(1 + \frac{W_S(u,v)}{W_N(u,v)}\right)\partial u\,\partial v \qquad (10)$$

Since the statistical properties of the photographic process, including image noise, may be assumed to be isotropic, and since for optimum coding the signal will also have the nature of an isotropic noise pattern, it is convenient to work in terms of the one-dimensional spatial frequency, w, where $w^2 = u^2 + v^2$, leading to

$$C = \pi \int_0^\infty \log_2 \left(1 + \frac{W_S(w)}{W_N(w)} \right) w \partial w \qquad (11)$$

If we assume that a natural scene has a power spectrum proportional to 1/w then

$$C \cong \pi \int_0^\infty \log_2 \left(1 + \frac{MTF^2(w)}{W_N(w)} \right) \partial w \qquad (12)$$

since $W_s(w) = \dfrac{MTF^2(w)}{w}$

Equation (11) illustrates the dilemma of evaluating the information capacity of the photographic process. Due to non-linearity the S/N ratio in terms of power spectra will only be constant over a limited input/output, exposure/density range. To keep equation (11) "exact", it is necessary to restrict it to small signals condition.

In an attempt to calculate the maximum information capacity of the photographic process as constrained between fog density and Dmax, Jones [*Jones*,1961] used Shannon's theorem for a power-limited channel and then made various ad hoc corrections to account for the fact that the photographic process is peak-limited. By usi for the respective information capacities. His results, along with other comparative values of interest, are summarized in Table II.

Table II. Information capacities of four films, and various comparative values, as estimated by Jones.

Film	Information capacity	Area for 1 bit	Information rate	Exposure for one bit	Comparative time for Hi-Fi system	Film area equiv. to one TV frame
	bits cm^{-2} $(\times 10^{-8})$	μm^2	bits erg^{-1} $(\times 10^{-8})$	photons $(\times 10^{-8})$	sec cm^{-2}	$cm^2/_{frame}$
Royal-X	0.449	200	26.5	8.18	3.01	2.98
Tri-X	0.845	118.4	7.35	29.4	5.1	1.76
Plus-X	1.86	53.8	6.45	33.6	11.2	0.8
Pan-X	2.85	35.0	7.45	29.2	17.2	0.52

Although manufacturers of film provide a speed rating for each film, usually no rating of image quality is given. While the speed rating is usually a satisfactory guide for the ordinary photographer, it is insufficient when choosing a film for scientific purposes where the greatest possible amount of information has to be recorded by the film.

We have defined Information Theory and we will use this powerful tool to obtain the capacity of a film to receive and store information.

II METHODS

The experimental setup process is based on the following steps:

2.1 Photograph preparation:

2.1.1 Setting up and determining exposure time.

Four films were used in the study, they are: T-MAX 100, T-MAX 400, T-MAX 3200 and TRI-X 400. T-MAX 100 has the finest grain, T-MAX 400 and TRI-X 400 have medium grain, and T-MAX 3200 has the largest grain of all four films. It would be interesting to know how they perform under normal exposure and constant flux.

Kodak T-MAX professional films are newer products, and TRI-X 400 is an "older" product of Eastman Kodak Company, so it is interesting to find if there is any difference between these two products.

Before we actually take a picture of the object, we must select the lens and film combination and also the shutter speed. The following equations are used to illustrate the variables needing to be controlled in the experiment.

$$\frac{t}{\left(F^{\#}\right)^{2}}=\frac{12.4}{LS} \qquad (13)$$

t : shutter speed

L · luminance in cdls/ cm^2

S : film speed

$F^{\#}$: numerical aperture

where $F^{\#}=f \;/\; D$ (14)

f : lens focal length

D : lens diameter

When the shutter speed and the total flux are constant, the following relationship can be established:

$$\sqrt{ASA} \;\; \alpha \left(F^{\#}\right)^2$$

If we let $F^{\#}$ =4 when ASA=100, then it follows that $F^{\#}$=8; when ASA=400 and $F^{\#}$=22; when ASA=3200. Also, D must be constant (i. e. D=6 mm) in order to have a proper range of focal length. When $F^{\#}$=4 we use a lens of focal length 25 mm, a focal length of 48 mm when $F^{\#}$=8, and a focal length of 132 when $F^{\#}$=22.

In order to have constant flux, the shutter speed setting (t_1) needs to be the same, while new shutter speeds t_3 and t_2 are set for normal exposure and $t_1 > t_2 > t_3$.

According to the above discussion, the following exposure conditions can be determined:

(1) For T-MAX100 film:

(a) A lens of 25 mm focal length and $F^{\#}$ of 4 was used to take a picture of each object.

(2) For T-MAX 400 film:

(a) A lens of 50 mm focal length and $F^{\#}$ of 8 was used to take a picture of each object.

(b) A lens of 25 mm focal length and $F^{\#}$ of 4 was used to take picture of each object. This step produced the same image size, in order to study the effect of different magnification on each print.

(3) For TRI-X 400 film:

(a) A lens of 50 mm focal length and $F^{\#}$ of 8 was used to take a picture of each object.

(b) A lens of 25 mm focal length and $F^{\#}$ of 4 was used to take a picture of each object. This step produced the same image size, in order to study the effect of different magnification on each print.

(4) For T-MAX 3200 film:

(a) A lens of 135 mm focal length and $F^{\#}$ of 22 was used to take a picture of each object.

(b) A lens of 25 mm focal length and $F^{\#}$ of 4 was used to take a picture of each object. This step produced the same image size, in order to study the effect of different magnification on each print.

To summarize the above statement the following combinations have been used for our project:

(1). Conditions to produce constant flux (fixed amount of photons):

	Focal Length	$F^{\#}$	Shutter speed (t_1)
T-MAX 100	25 mm	4	1/30 sec
T-MAX 400	50 mm	8	1/30 sec
TRI-X 400	50 mm	8	1/30 sec
T-MAX 3200	135 mm	22	1/30 sec

(2). Conditions to give normal exposure:

	Focal Length	$F^{\#}$	Shutter speed (t_1)
T-MAX 400	25 mm	4	1/250 sec
TRI-X 400	25 mm	4	1/250 sec
T-MAX 3200	25 mm	4	1/1000 se

(3). The orders of the pictures taken for the scenes are : gray card, "simple" scene, gray card, "busy" scene.

Photographs attached:

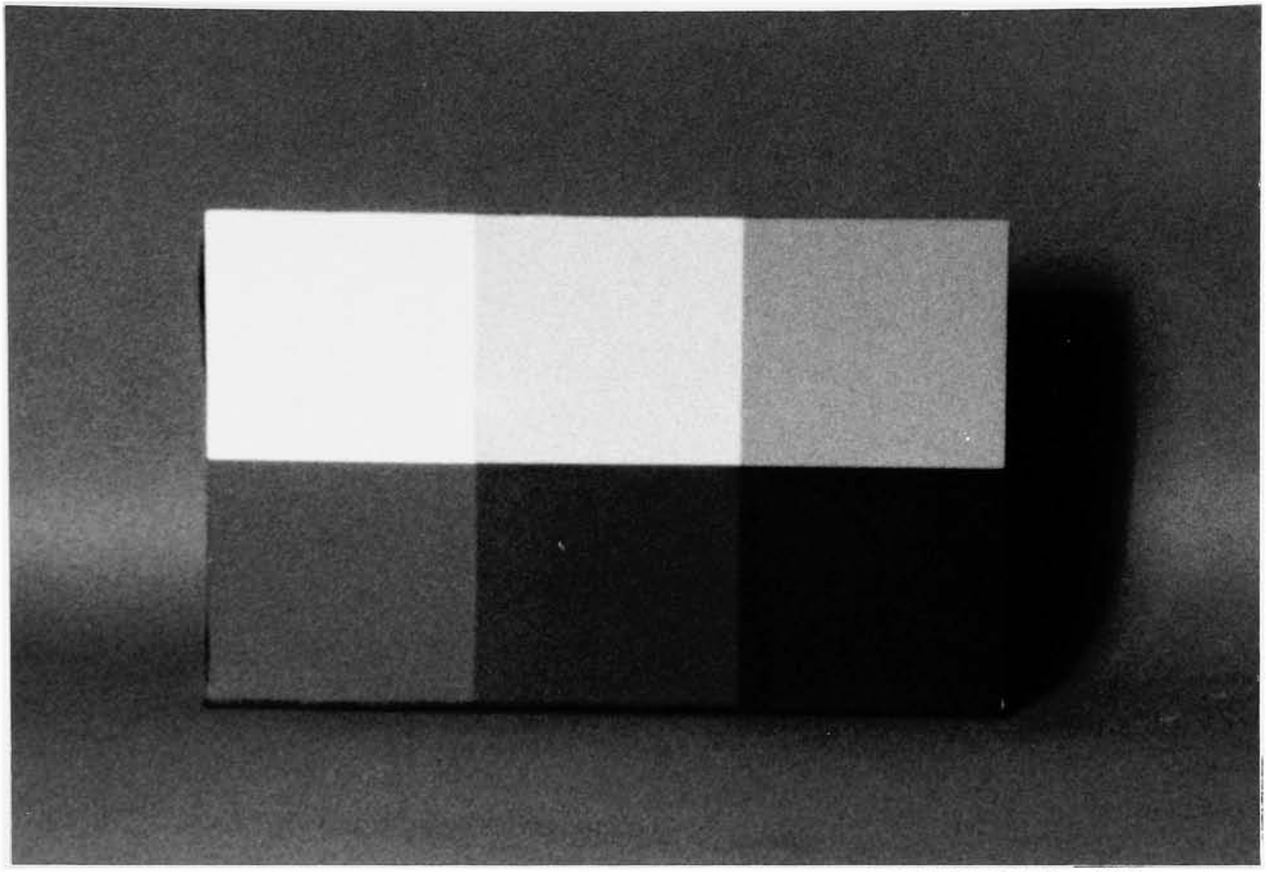


Image from T-MAX 100 film / 25 mm lens

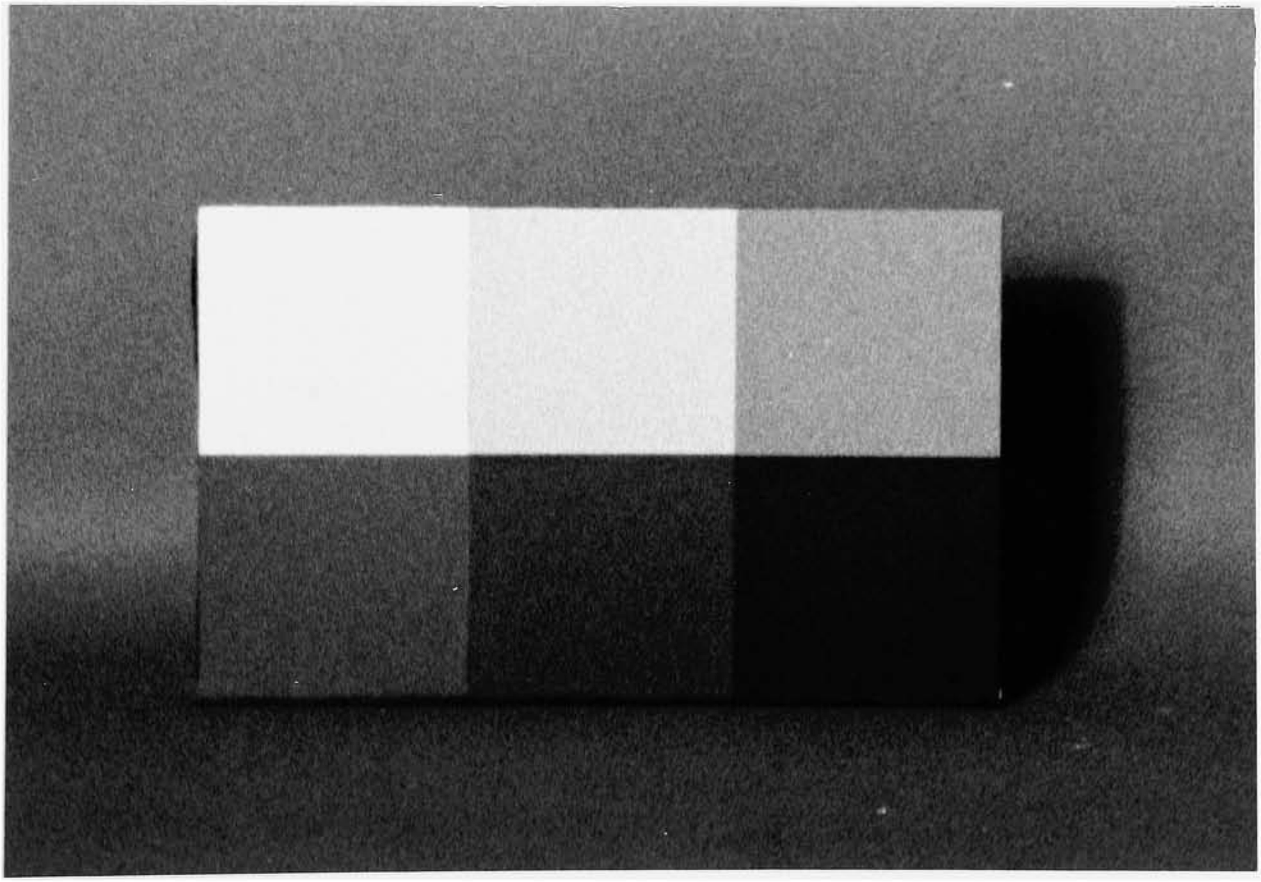


Image from T-MAX 400 film / 25 mm lens

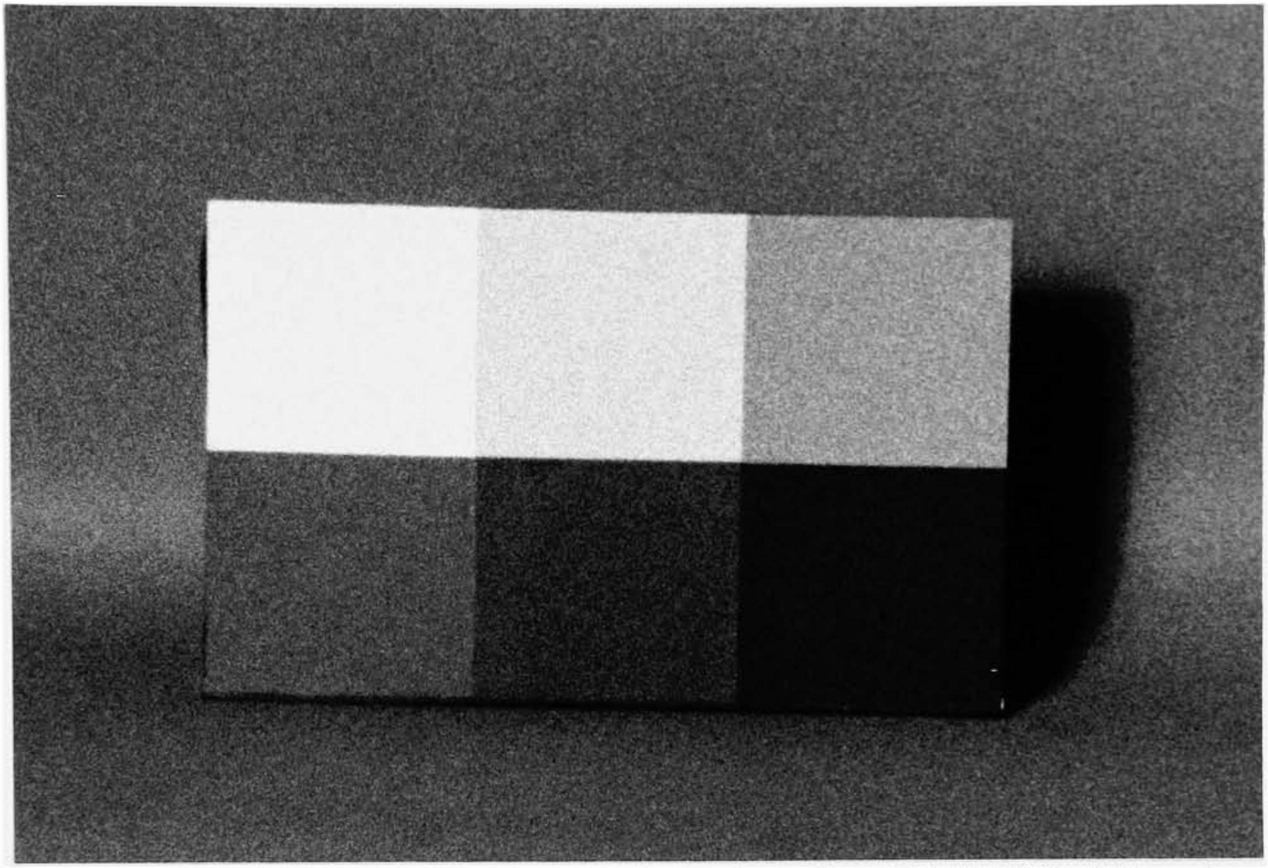


Image from TRI-X 400 film / 25 mm lens

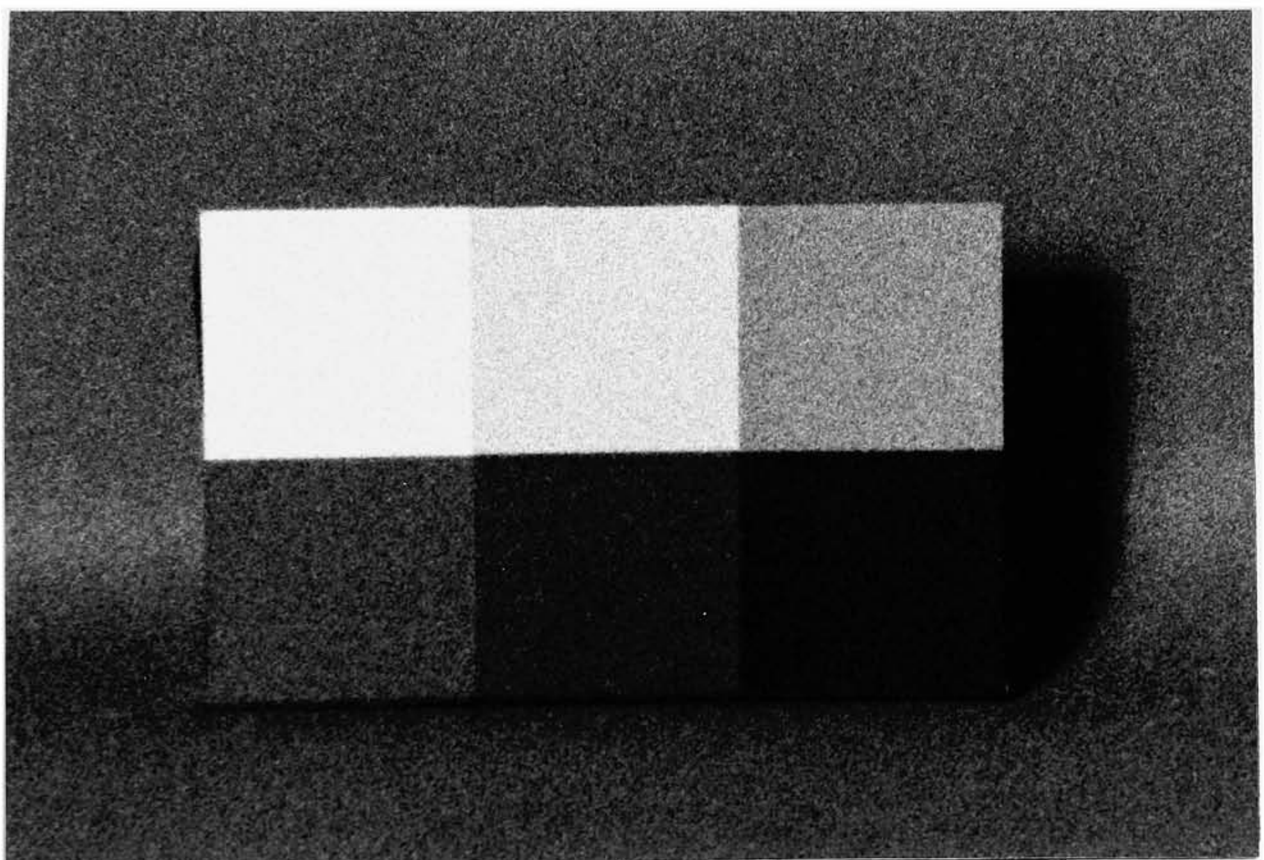


Image from T-MAX 3200 film / 25 mm lens

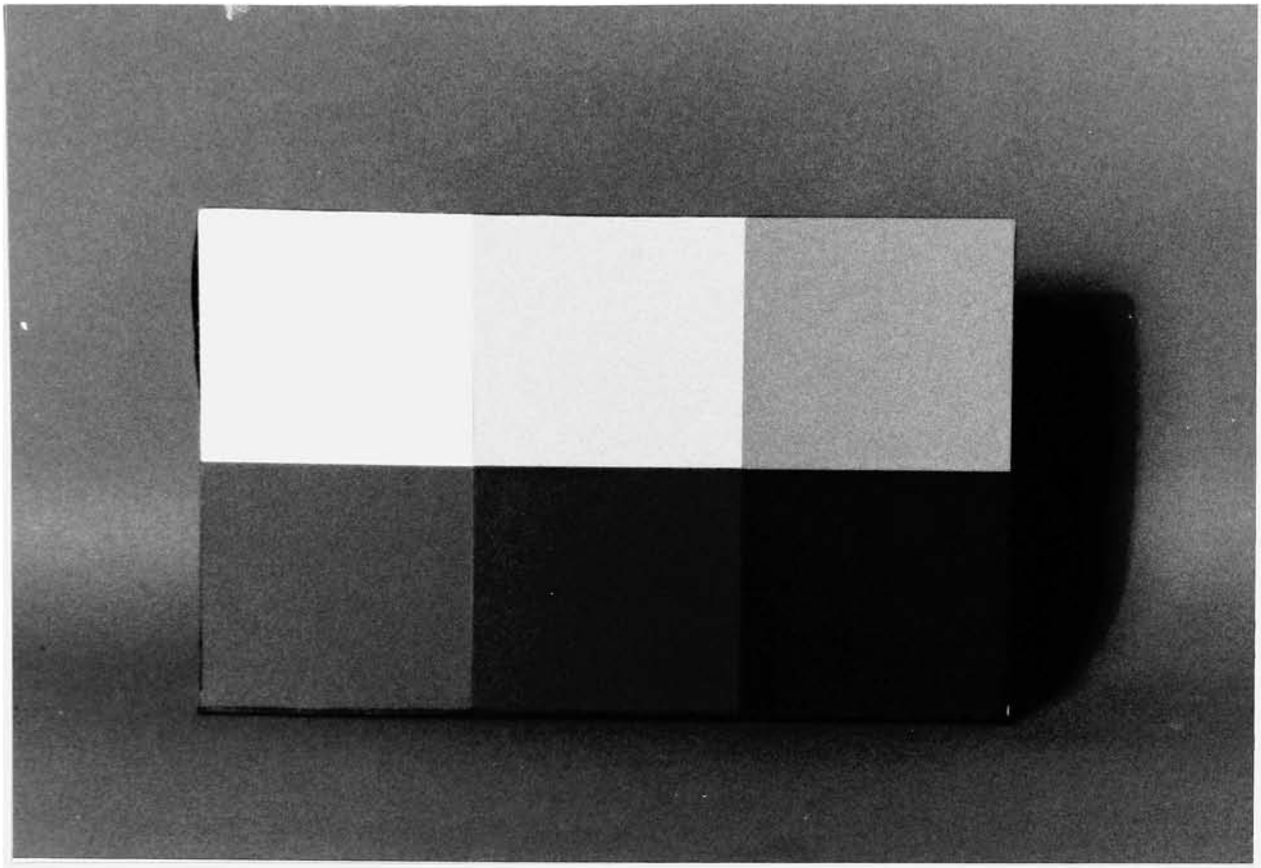


Image from T-MAX 400 film / 50 mm lens

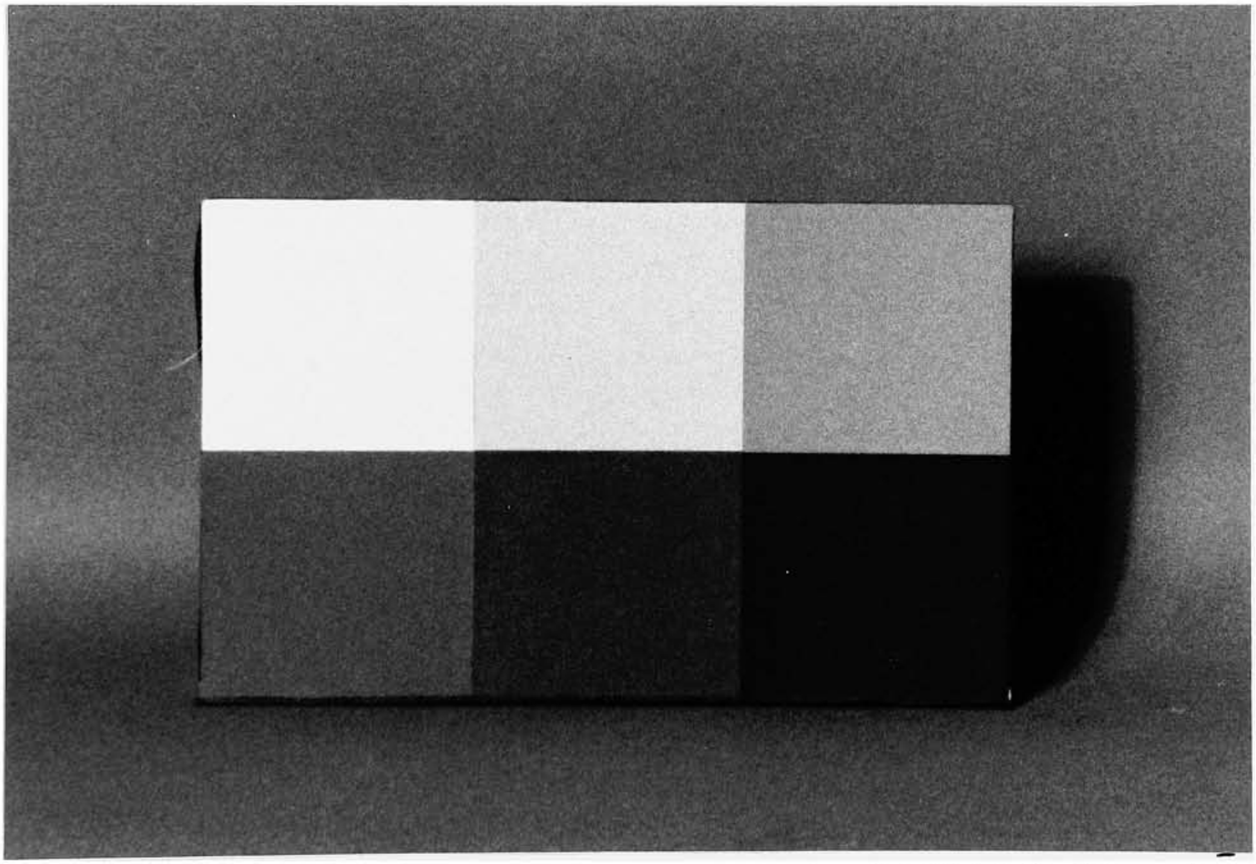


Image from TRI-X 400 film / 50 mm lens

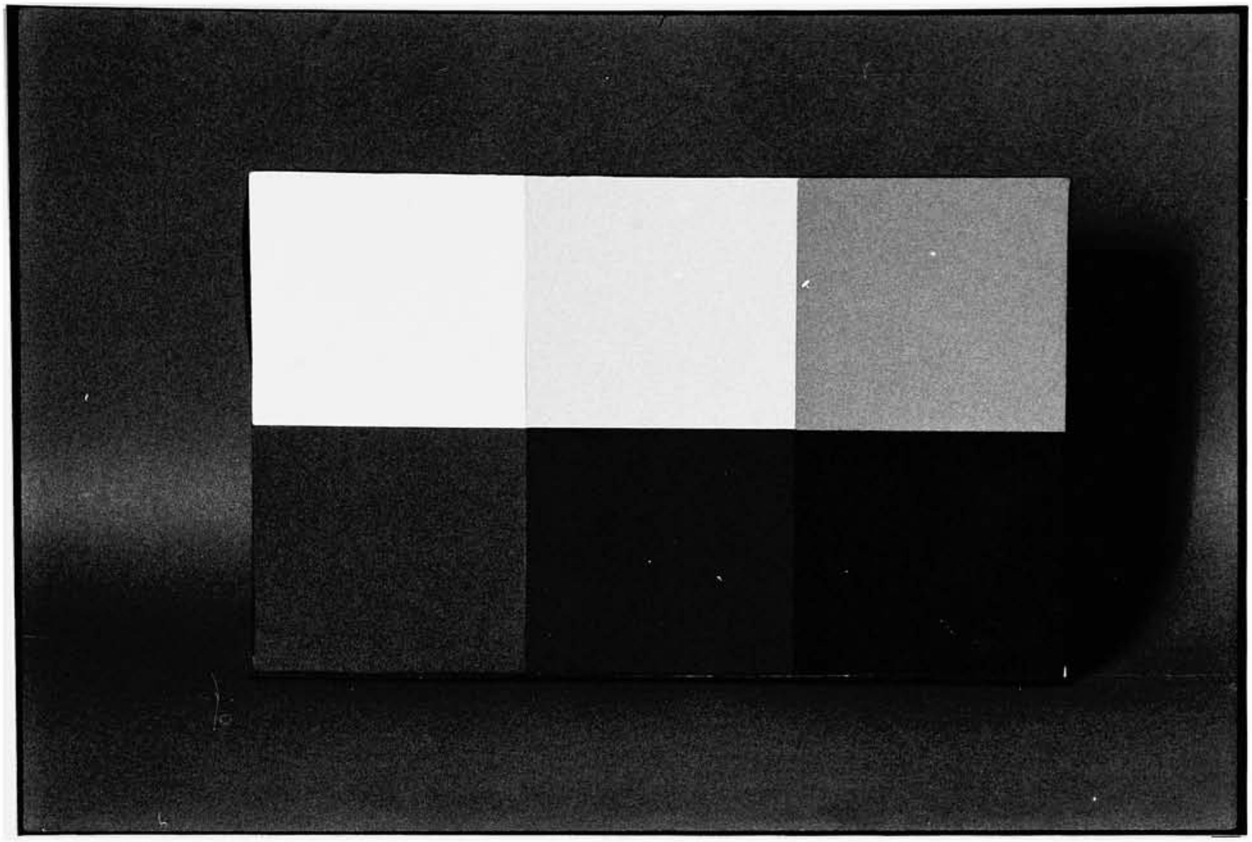


Image from T-MAX 3200 film / 135 mm lens

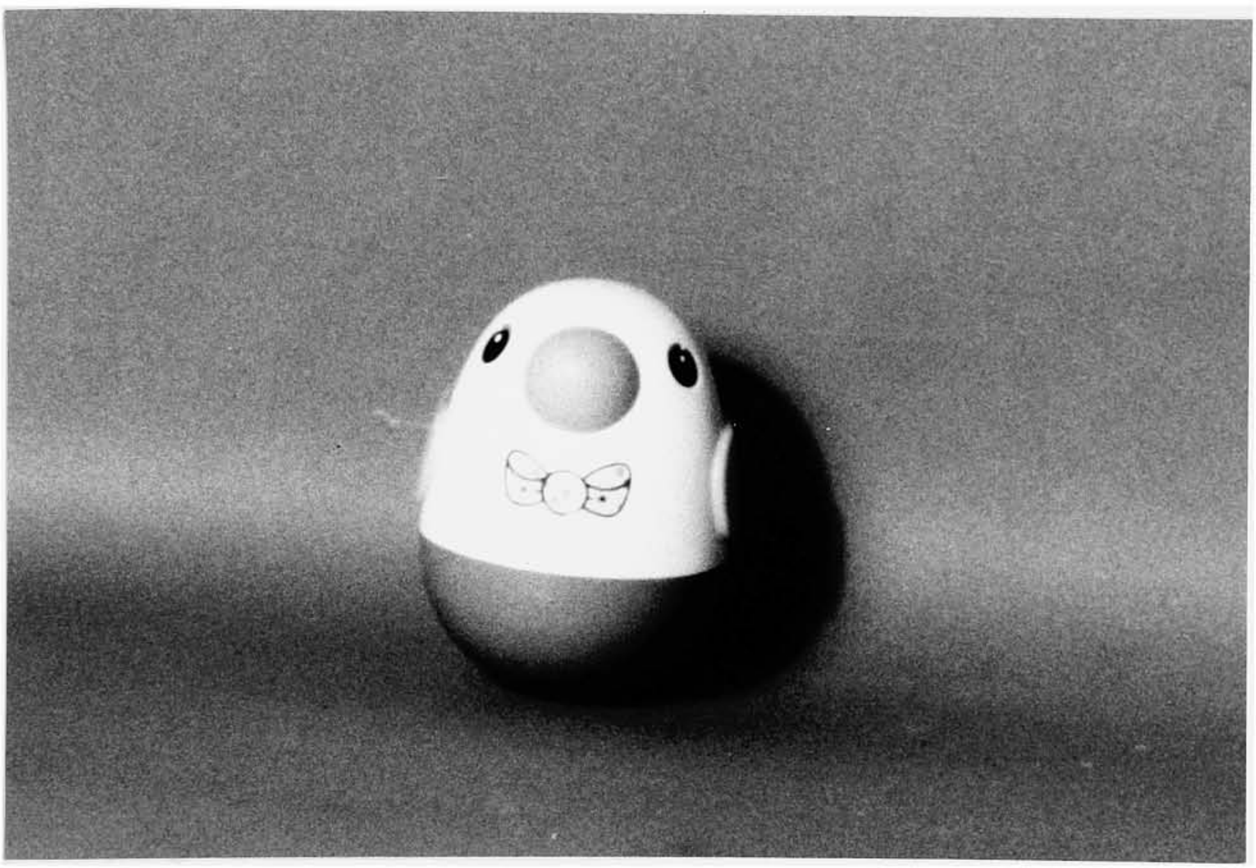


Image from T-MAX 100 film / 25 mm lens

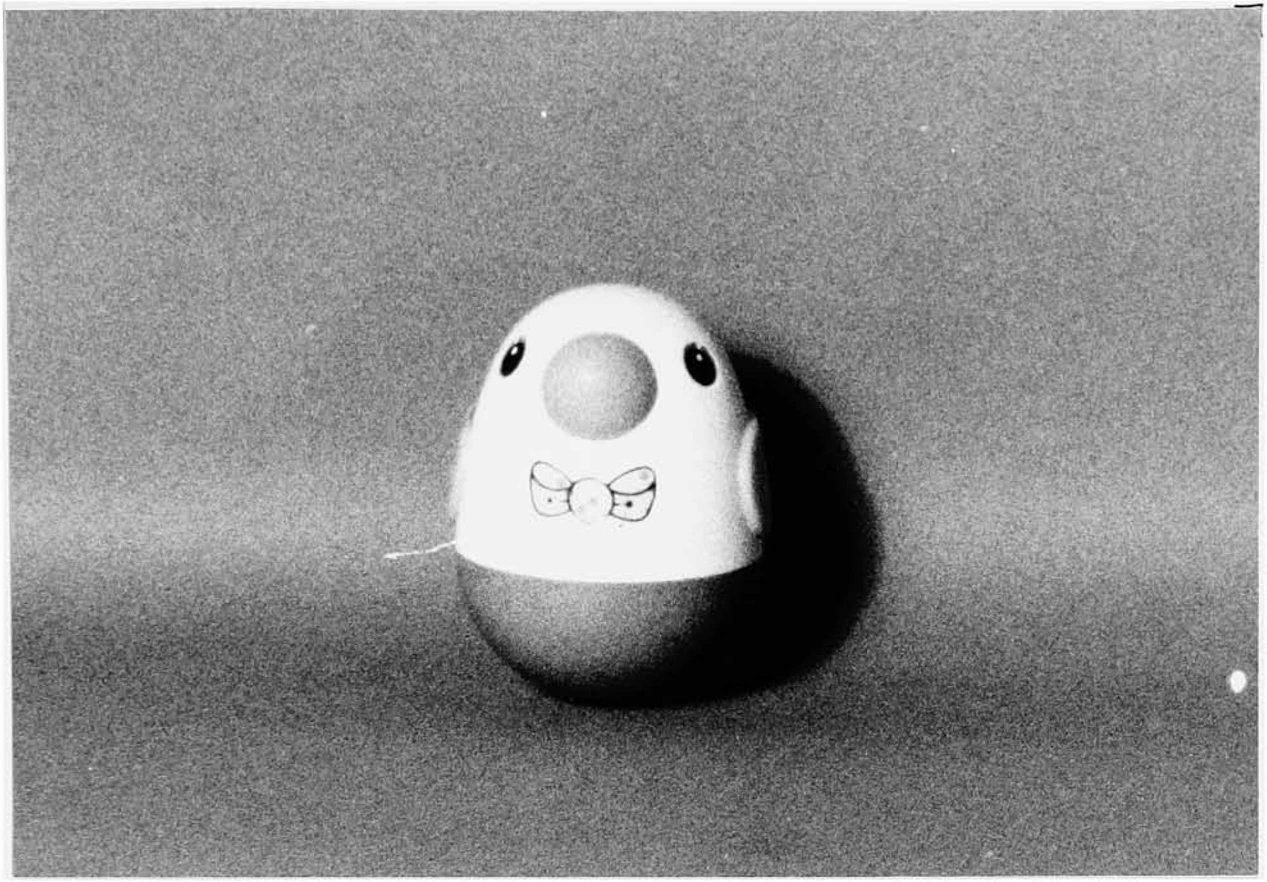


Image from T-MAX 400 film / 25 mm lens

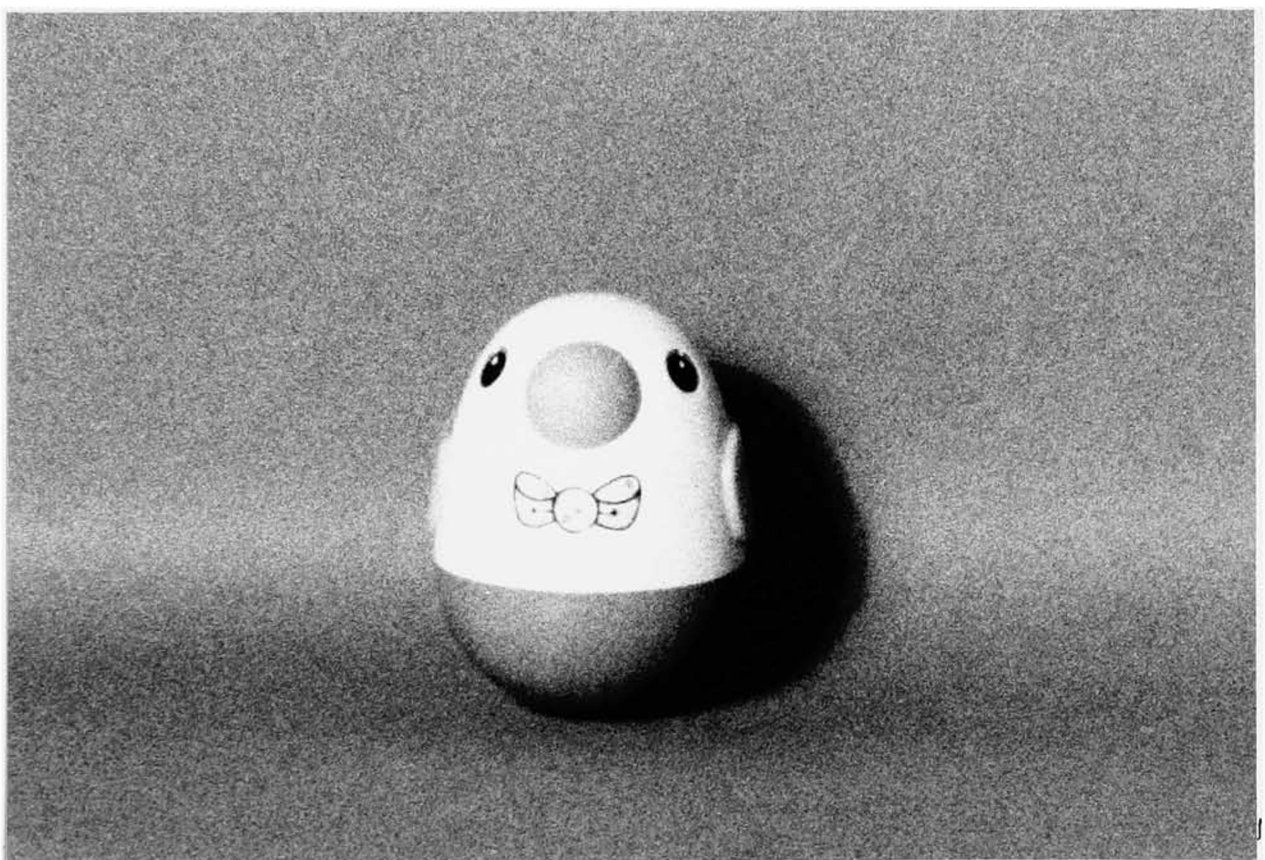


Image from TRI-X 400 film / 25 mm lens

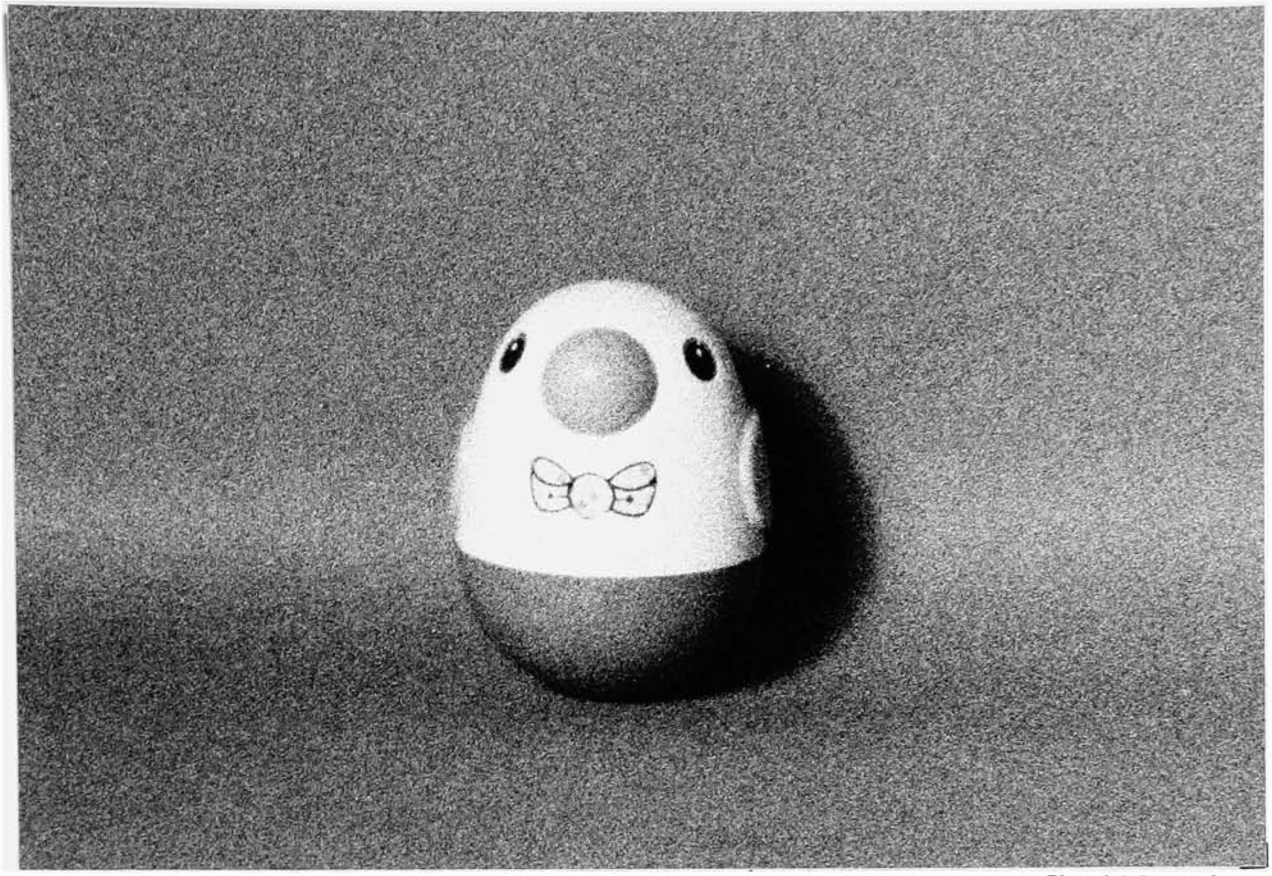


Image from T-MAX 3200 film / 25 mm lens

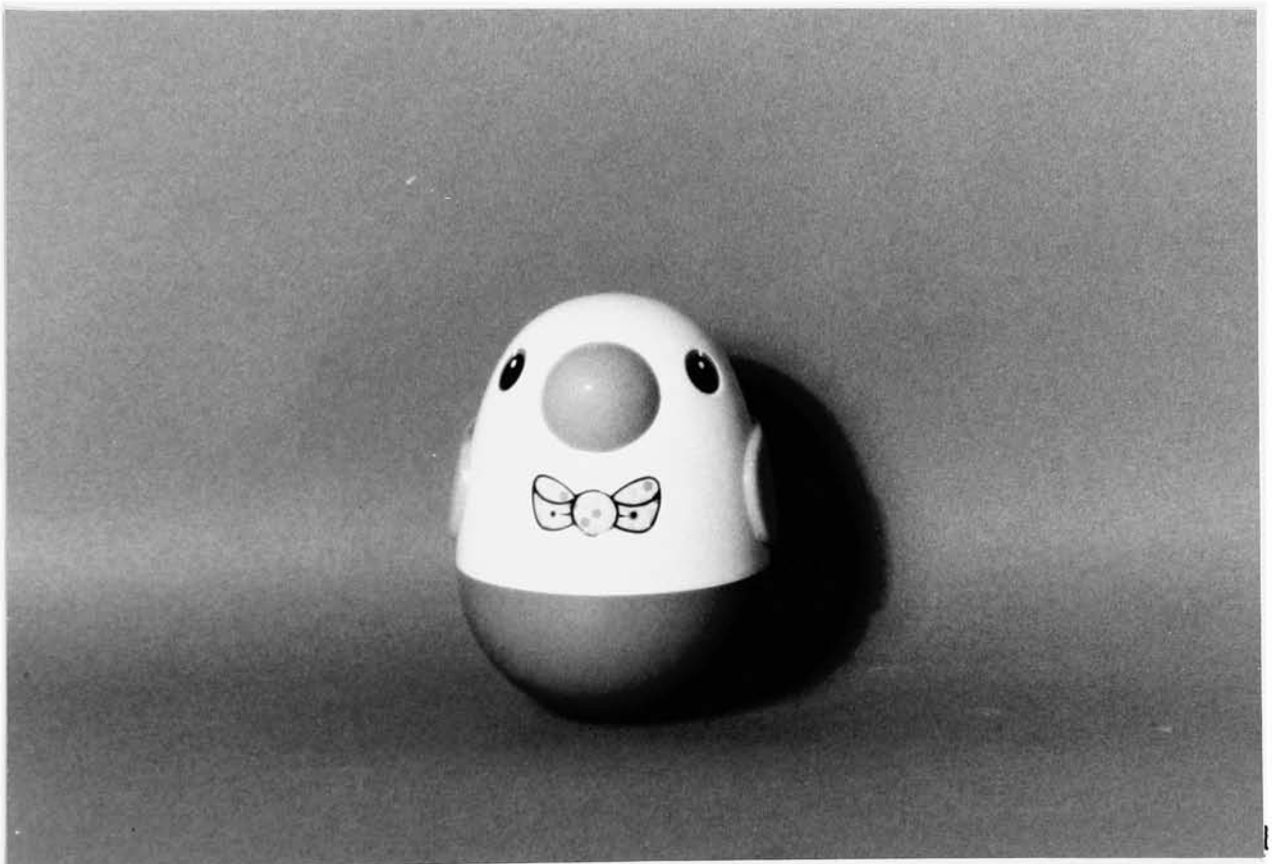


Image from T-MAX 400 film / 50 mm lens

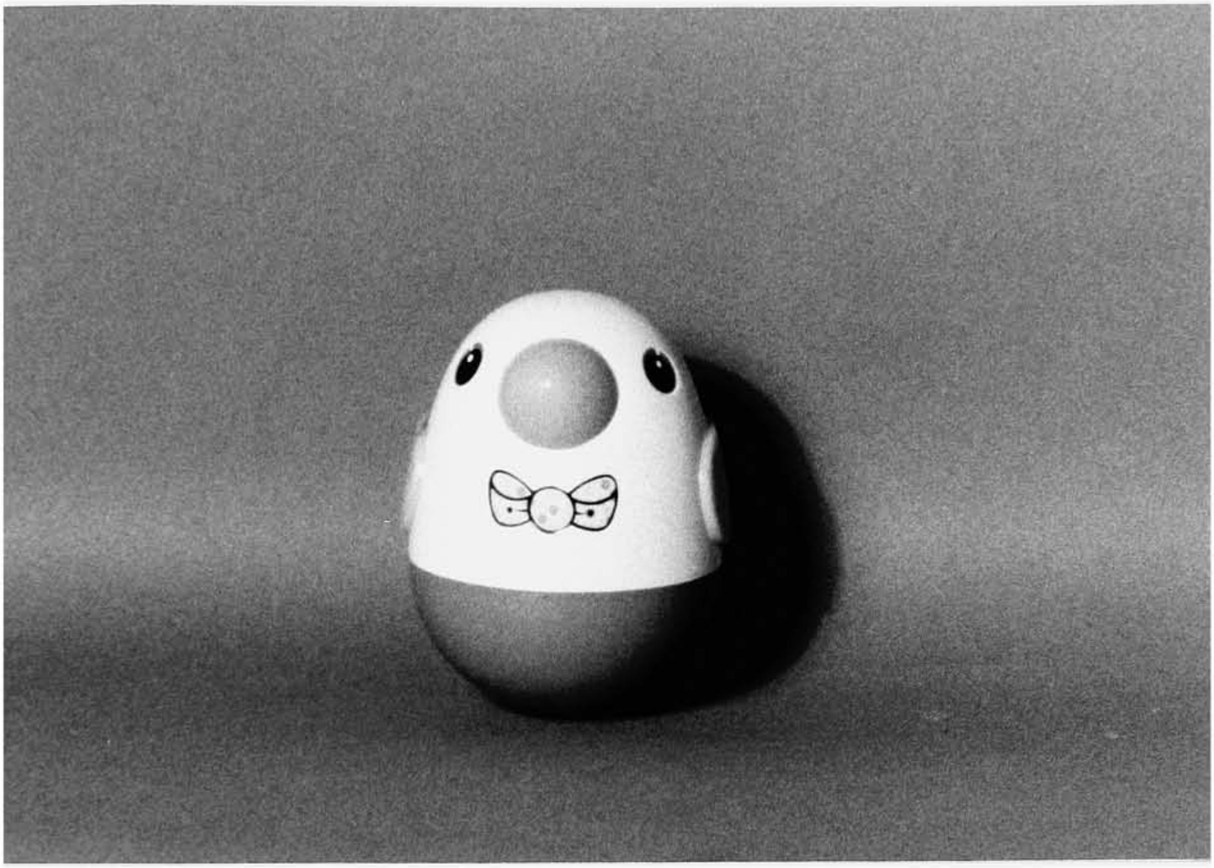


Image from TRI-X 400 film / 50 mm lens

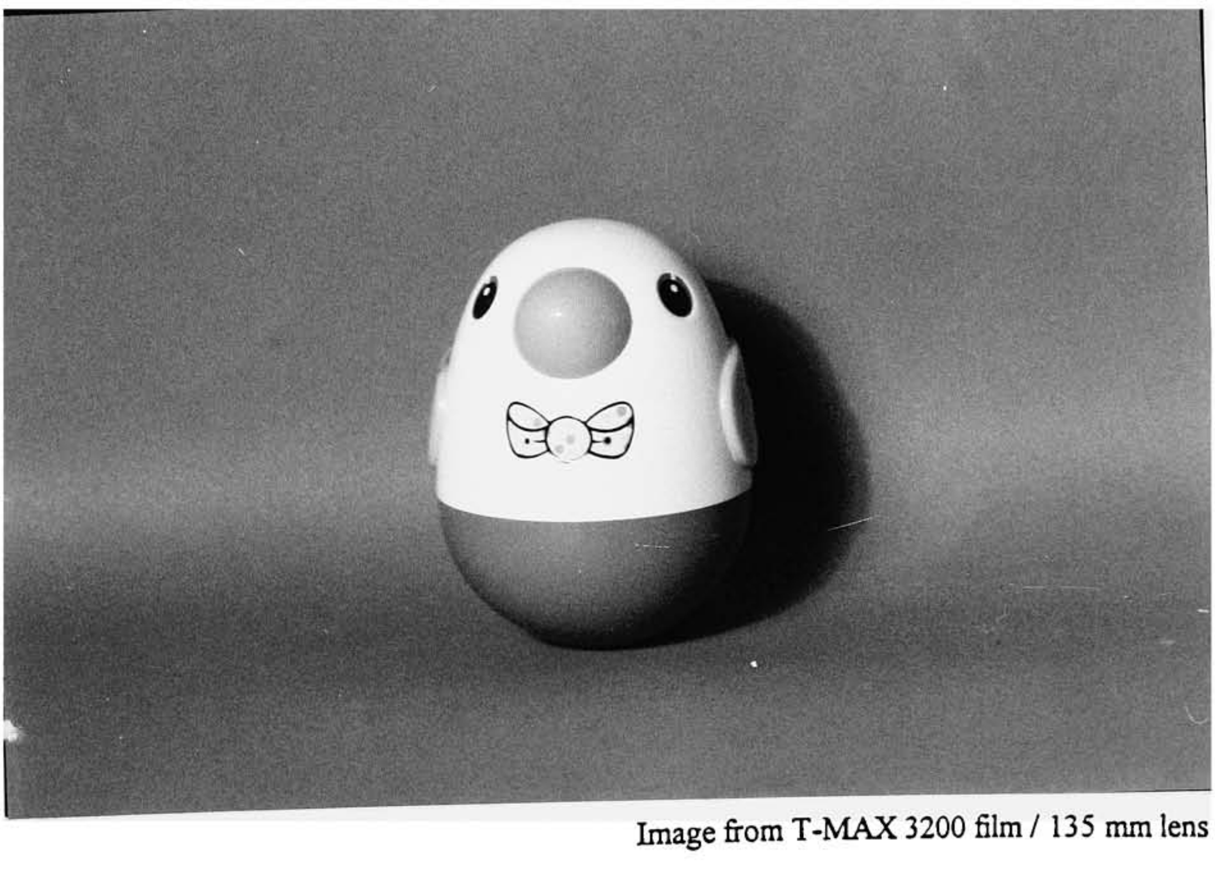


Image from T-MAX 3200 film / 135 mm lens

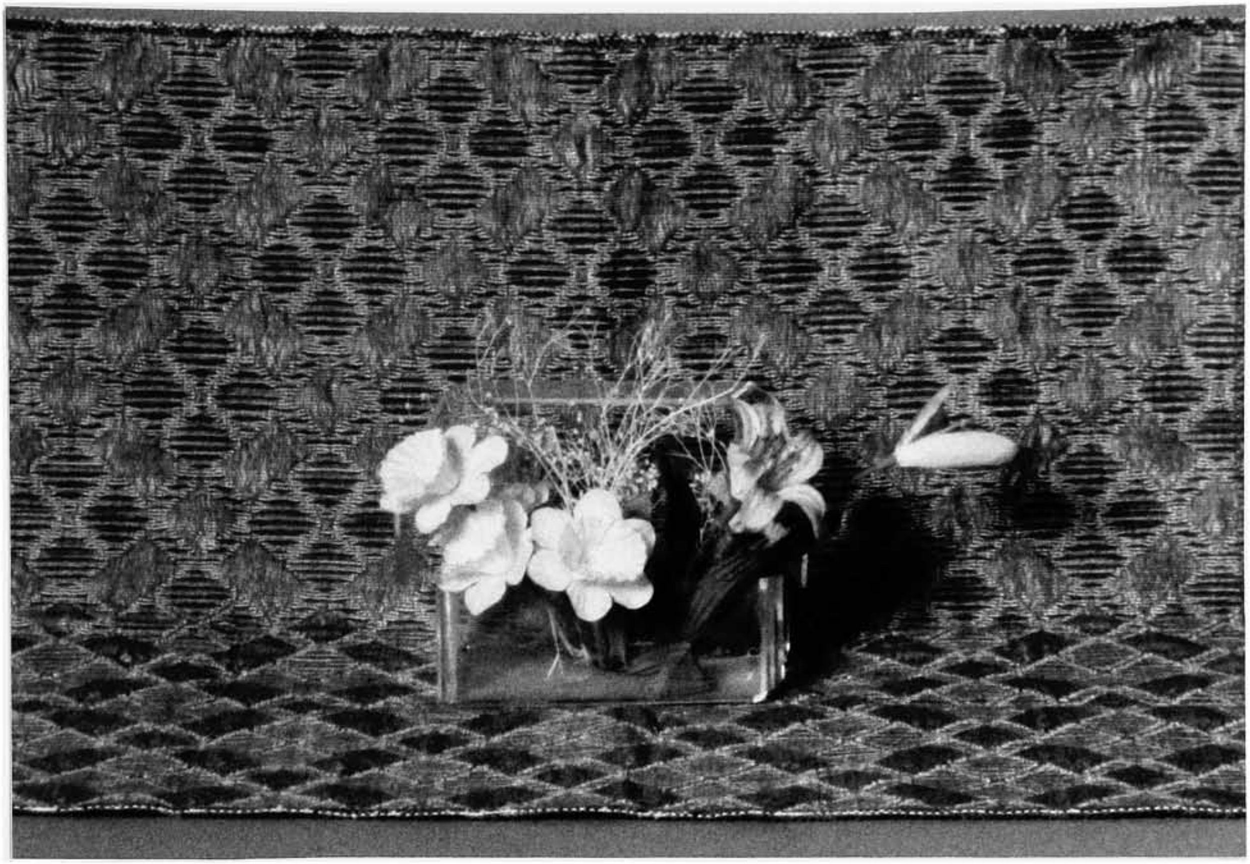


Image from T-MAX 100 film / 25 mm lens

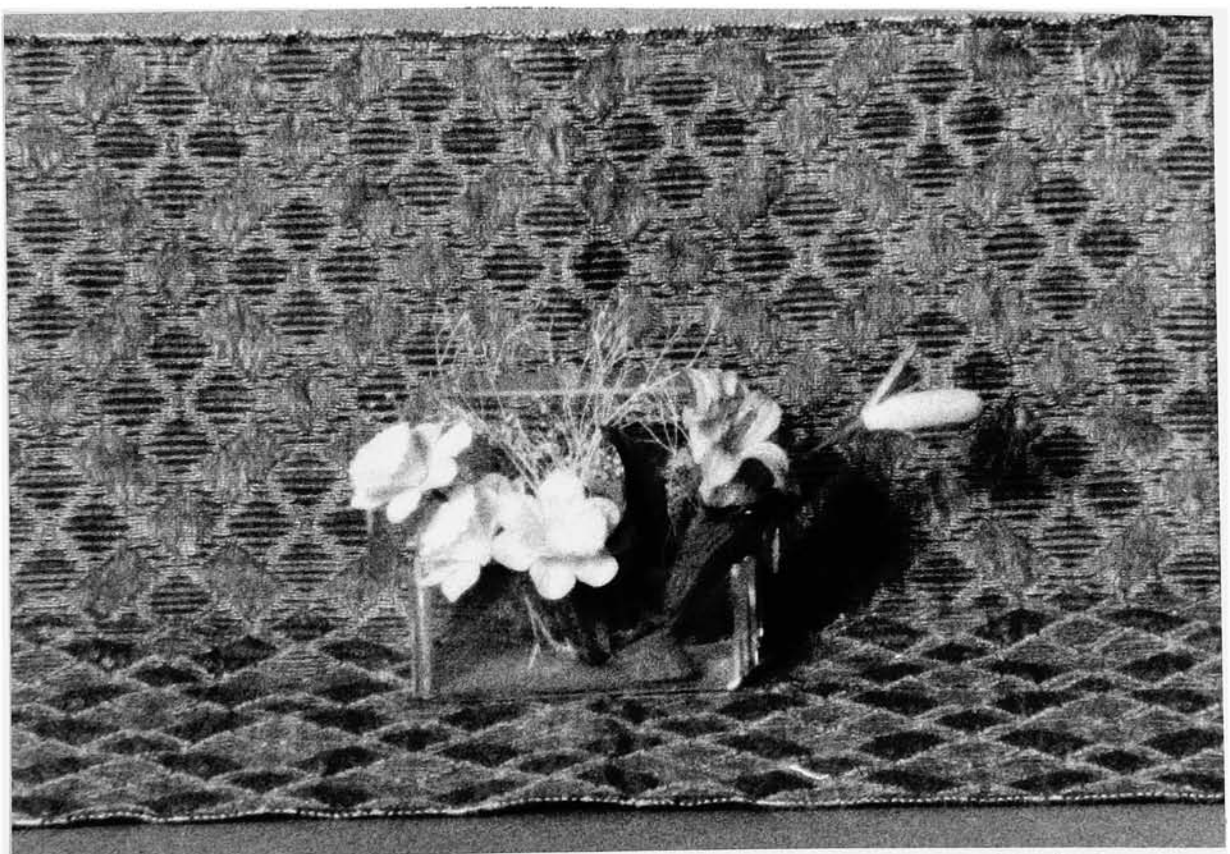


Image from T-MAX 400 film / 25 mm lens

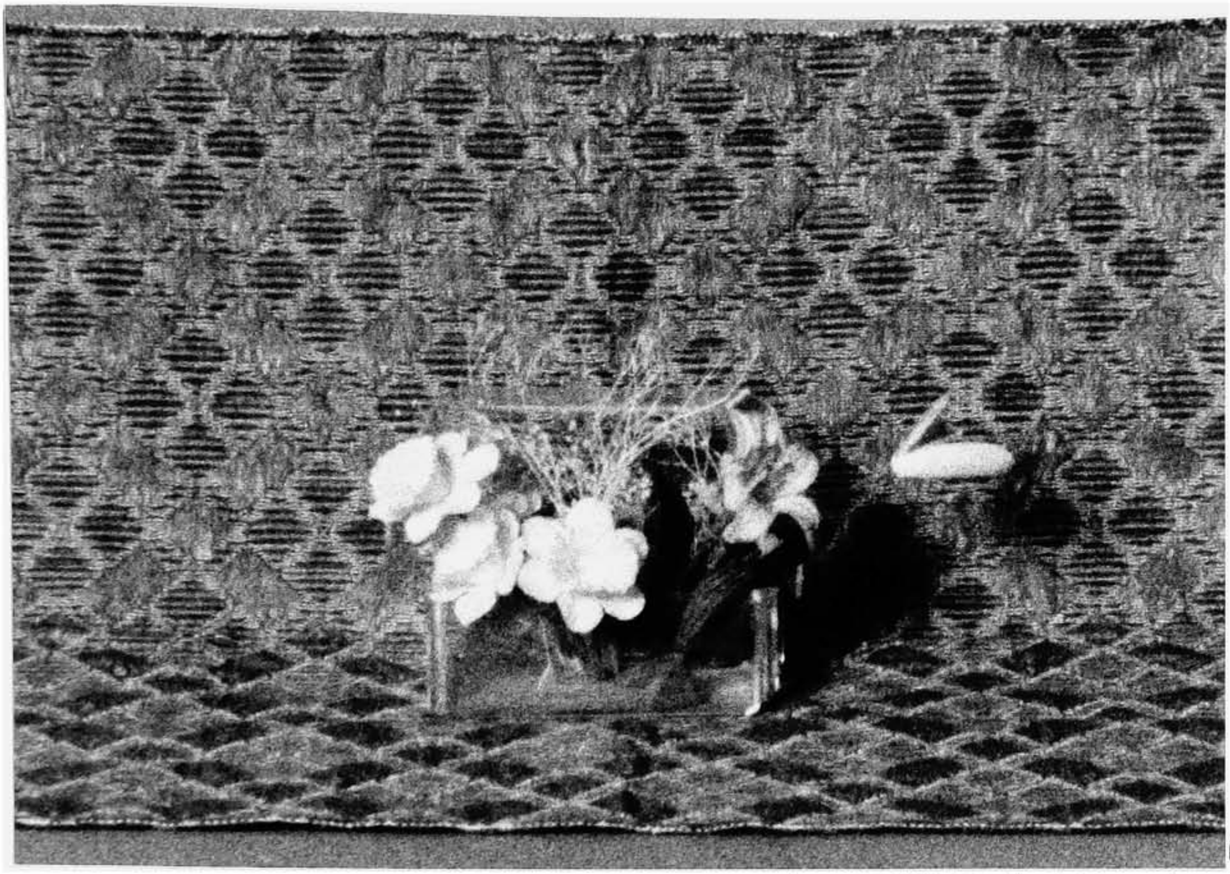


Image from TRI-X 400 film / 25 mm lens

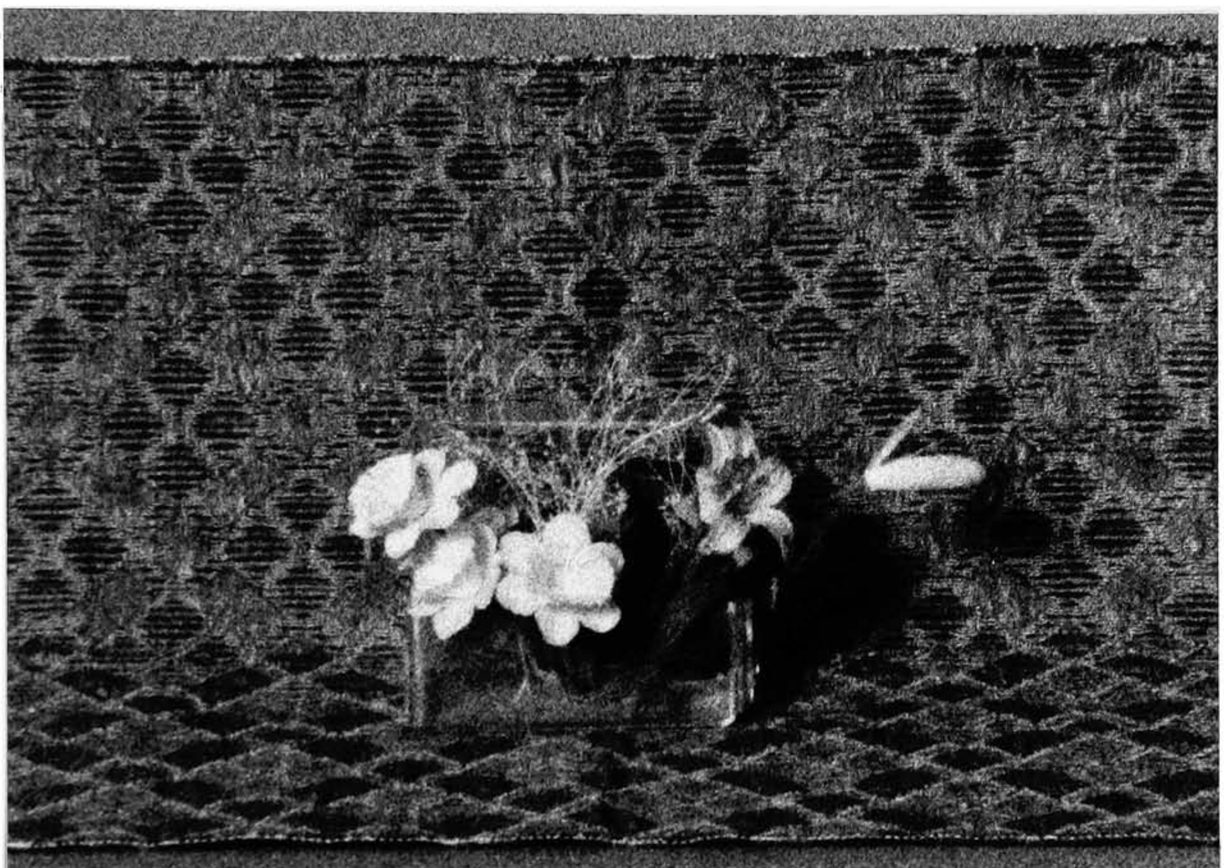


Image from T-MAX 3200 film / 25 mm lens

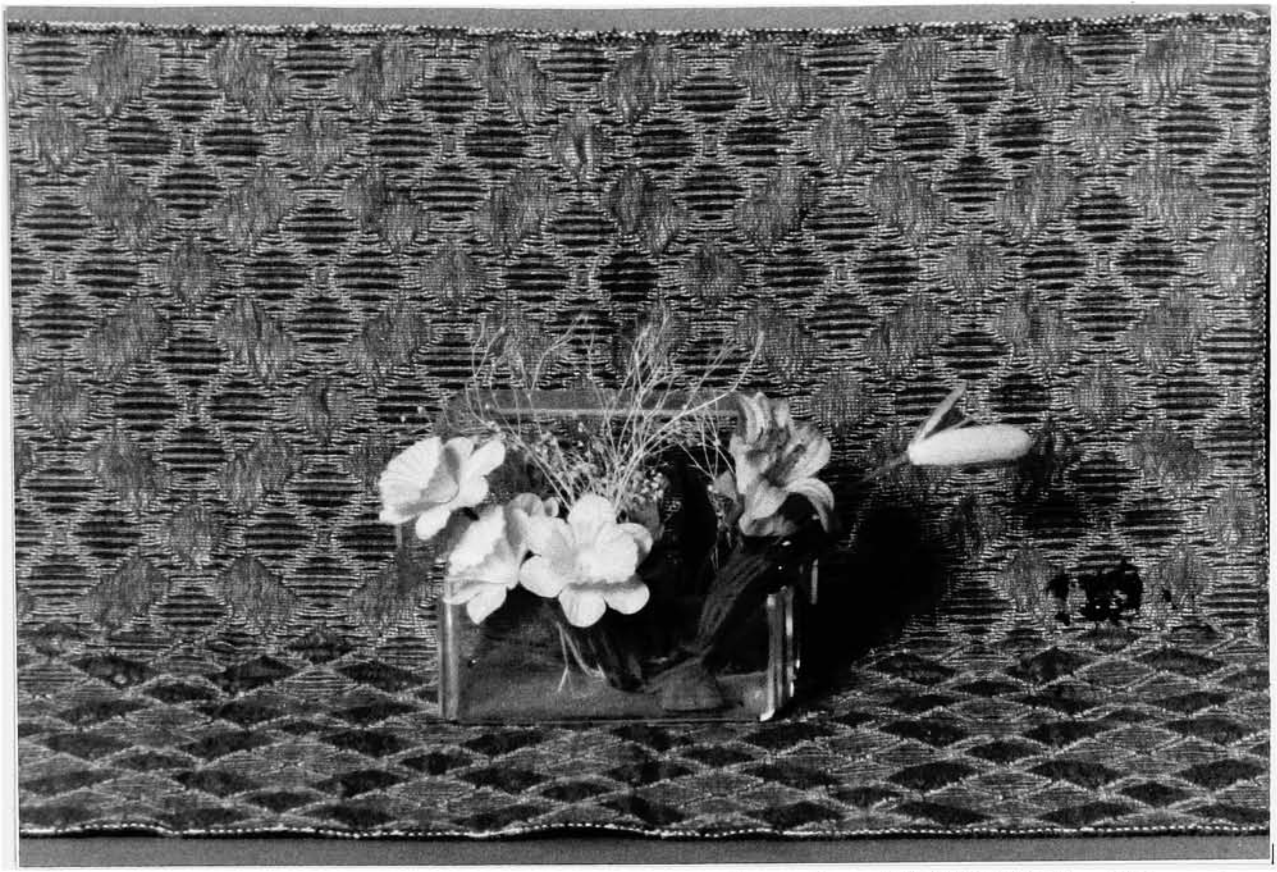


Image from T-MAX 400 film / 50 mm lens

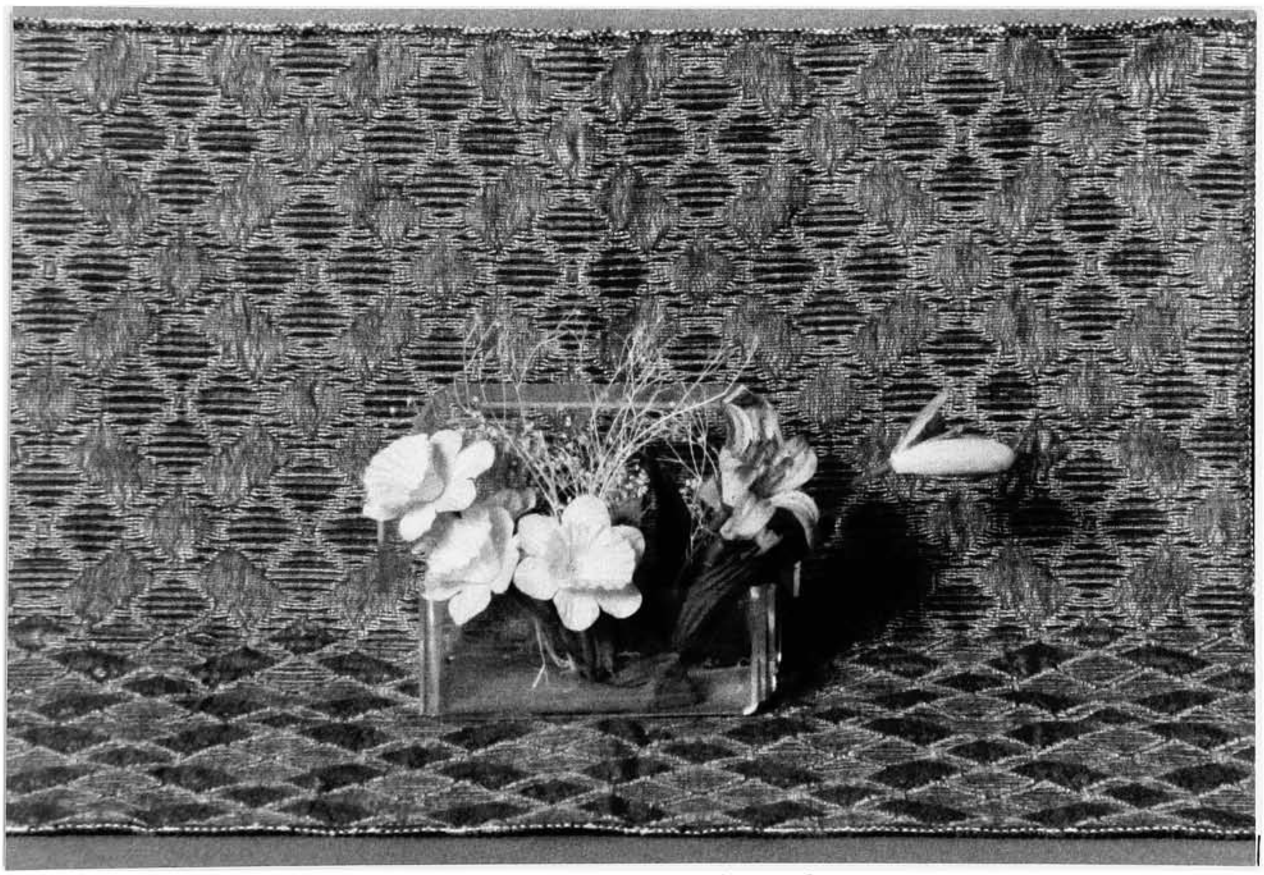


Image from TRI-X 400 film / 50 mm lens

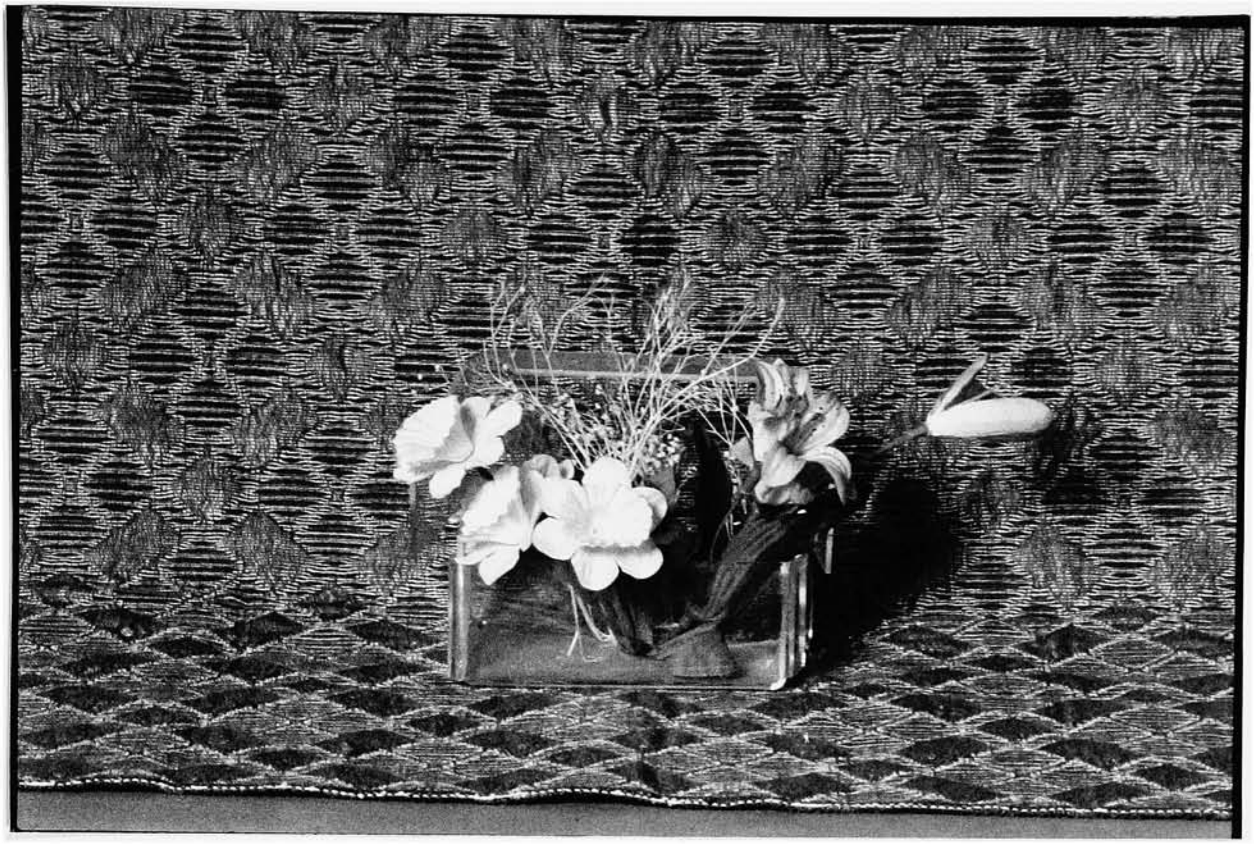


Image from T-MAX 3200 film / 135 mm lens

2.1.2 Developing film and photographic paper.

(1) All films were developed at the R.I.T. campus, using the Kodak Versamat Film Processor V-5N for developing the films.

(a) Process speed for T-MAX 100 was 2.2 ft / min.

(b) Process speed for T-MAX 400 was 2.75 ft / min.

(c) Process speed for TRI-X 400 was 1.5 ft / min.

(d) Process speed for T-MAX 3200 was 2.2 ft / min.

(2) The following conditions were used to project images from negative to photographic paper:

Table III. Conditions used for this project

(1) When 25 mm lens was used:

H_1 & H_2: 371/2" & 53/4"

Films	Objects	Filter	Exposure Time	x Magnification
T-MAX 100	Gray Card	3.5	27 sec	631.9
T-MAX 100	Egg	4.0	44 sec	760.8
T-MAX 100	Flower	4.0	48 sec	860.4
T-MAX 400	Gray Card	4.0	38 sec	608.8
T-MAX 400	Egg	4.5	27 sec	597.3
T-MAX 400	Flower	4.5	27 sec	632.2
TRI-X 400	Gray Card	3.5	28 sec	601.4
TRI-X 400	Egg	4.0	46 sec	784.0
TRI-X 400	Flower	4.0	46 sec	632.2
T-MAX 3200	Gray Card	4.0	37 sec	711.5
T-MAX 3200	Egg	4.0	31 sec	784.0
T-MAX 3200	Flower	4.0	33 sec	632.2

(2) When 50 mm lens was used:

H_1 & H_2: 371/2" & 53/4"

Films	Objects	Filter	Exposure Time	x Magnification
T-MAX 400	Gray Card	4.0	11.5 sec	190.4
T-MAX 400	Egg	4.0	10.0 sec	196.0
T-MAX 400	Flower	4.0	10.0 sec	215.1
TRI-X 400	Gray Card	3.5	9.0 sec	190.4
TRI-X 400	Egg	3.5	7.5 sec	196.0
TRI-X 400	Flower	3.5	7.0 sec	215.1

(3) When 135 mm lens was used:

H_1 & H_2: 371/2" & 53/4"

Films	Objects	Filter	Exposure Time	x Magnification
T-MAX 3200	Gray Card	4.5	7.7 sec	21.1
T-MAX 3200	Egg	4.0	6.3 sec	21.5
T-MAX 3200	Flower	4.5	7.1 sec	21.4

(3). All photographic paper was developed at the R.I.T. campus by using a Kreonite B/W Process

(4). All negatives were printed to the same image size.

2-2 Evaluating image quality of photographs

The successive categories method was used in this project for statistical analysis. The underlying assumptions of the law of successive categorical judgments have been stated by Togerson (1958) [*Togerson*,1958]:

(1) The psychological continuum of the subject can be divided into a specified number of order categories or steps.

(2) Owing to various and sundry factors, a given category boundary is not necessarily always located at a particular point on the continuum. Rather, it also projects a normal distribution of positions on the continuum. Again, different category boundaries may have different mean locations and different dispersions.

(3) The subject judges a given stimulus to be below a given category boundary whenever the value of the stimulus on the continuum is less than that of the category boundary.

There are many forms of category scaling and a wide variety of experimental techniques and data reduction algorithms that have been used in category scaling. A common experimental method of category scaling was used in this project to gather data about the image quality of twenty-one photographs. Thirty-three observers participated in this project. They were asked to rate the overall image quality of each photograph on a 7-point scale. The instructions and results were as follows:

2-2-1 Instrustions to observers

INSTRUCTIONS TO OBSERVERS

You will be shown a number of photographs. We would like you to make a judgment on the image quality of the photograph, and give a rating for the print.

Please do not directly touch the photographs.

Do not consider composition.

Ignore scratches, dirt, and any physical defects in the photograph.

The viewing distance should not exceed 12 inches.

Please express your opinion using a scale of number from 1 to 7 where 7 represents unusable and 1 represents excellent image quality. Numbers between 1 and 7 represent equal intervals of image quality. The categories used in these experiment are:

(1) Excellent

(2) Very Good

(3) Good

(4) Acceptable

(5) Unsatisfactory

(6) Poor

(7) Unusable

You may not use fractions or decimals; you must use integers. The integers should be from 1 to 7; no other integers may be used.

2-2-2 Results from evaluating the image quality of photographs

(1) An image quality assessment by the observers was performed in a period of three months. The observer were randomly chosen, among them were: professional people, students, and ordinary observers. The photographs were randomly presented to each observer for evaluation. The randomness of the photograph is important. This process allowed control of accuracy of the rating data. After collecting all the data from the viewers a statistic analysis is performed to generate mean value (m) and standard deviation (δ)

(2) Thirty three viewers were asked to make a judgment on the image quality of the photograph and a rating was given to the photograph. A rating of "1" means excellent, and "7" means unusable.

(3) Data: Appendix 1

The abbreviations are as follow:

gray card: G, Egg: E, Flower: F

T-MAX100 / 25 mm: 1, T-MAX 400 / 25 mm: 2, T-MAX 3200 / 25 mm: 3,

TRI-X 400 / 25 mm: 4, TRI-X 400 / 50 mm: 5, T-MAX 400 / 50 mm: 6,

T-MAX 3200 / 135 mm: 7

(4) A statistical analysis was performed to evaluate the data.

(5) The original results were transferred to a new scale where the original 1 is represented by 1 and original 7 is represented by 0. These new numbers are identified as "Ranking"

$$\text{Ranking (R)} = 116.666\text{-}16.666 \times \text{mean (m)} \qquad (15)$$

Table IV Statistic data for "Grey Card"

	G1	G2	G3	G4	G5	G6	G7
Mean (m)	3.55	4.15	5.30	4.52	3.0	2.30	1.79
Ranking (R)	0.575	0.475	0.283	0.413	0.666	0.783	0.868
Standard Deviation (δ)	0.99	1.08	1.34	1.13	0.85	0.90	0.73

Table V Statistic data for " Egg "

	E1	E2	E3	E4	E5	E6	E7
Mean (m)	3.97	4.73	5.36	4.97	3.36	2.42	1.88
Standard Deviation (δ)	1.03	1.11	1.20	1.11	1.07	0.99	1.01

Table VI Statistic data for " Flower "

	F1	F2	F3	F4	F5	F6	F7
Mean (m)	3.52	4.52	5.39	4.97	3.18	3.21	1.91
Standard Deviation (δ)	0.93	1.13	1.13	1.19	1.03	1.01	0.71

2-3 Calculating MTF of photographs

Many studies in the field of image quality definition have noticed that a perceptible difference in image quality can be obtained by changing the scale of the point spread function. The quality of a visual image is related to the scale of the image on the retina. The human visual system has a modulation transfer function (MTF) with broad peak response at 6 cycles per degree (cpd). Image quality rank can be computed if the "true" eye MTF is used in the calculation of quality rank. In fact, computations that use only the one-dimensional MTF have proven quite successful in predicting quality rank for two-dimensional image structure. These successes suggest that the one-dimensional treatment includes the proper weighting function to describe the two-dimensional visual properties of the image. Subjective Quality Factor (SQF) tells us that image quality is related to logarithmic spatial frequency weighting of the system optical transfer function (OTF). Specifically, image quality correlates with the area under the system OTF when displayed on a log spatial frequency scale.

A Crosfield Magnascan 636 reflection drum scanner was used to scan seven of the gray card photographs. All photographs were carefully aligned and scanned at 18 pixels / mm. The data were then read in Photoshop 4-5 to generate raw data for granularity and MTF calculation. MTFs' of each print were calculated according to the following equations:

$$\ell(x) = \frac{\partial e(x)}{\partial x} \qquad (16)$$

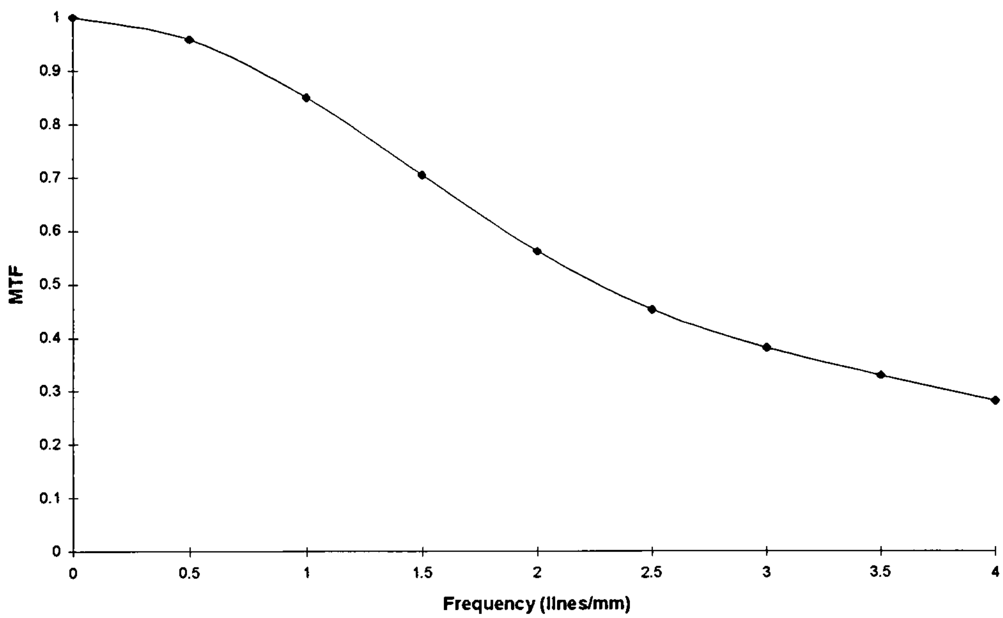
$$\text{and } OTF(f) = \int_{-\infty}^{\infty} \ell(x) e^{i2\pi fx} \partial x \qquad (17)$$

$$MTF(f) = |OTF(f)| \qquad (18)$$

A routine was written in Mathcad 4.0 and used to do the calculation. The program and calculations are shown in Appendix-3.

The MTF curve for the print generated from T-MAX 100 film and 25 mm lens combination is as following:

Figure 3 MTF of final print by using T-Max 100 film w/25 mm lens



2-4 Determining granularity

Photoshop 4-5 was used to obtain the granularity data, one set of data was obtained with a low pass filter and the second set data was obtained without a filter. The digital data were scaled as an integers between 0 and 255. A mean of 128 was used in the equation below. The following equation was used to transform original granularity data to "New" granularity data:

$$G_{New} = \left(\log \frac{Noise(\sigma)}{White} \right) + \log 2 \qquad (19)$$

$$Noise(\sigma) = \sqrt{\sum_{pixels} \frac{(signal - \mu)^2}{\#ofpixels}} \qquad (20)$$

where white = 255

A linear relationship was developed between Information Theory and σ_D to predict the subjects averaged response for each set of prints. A second linear relationship was developed between SQF and σ_D to predict the subjects averaged response for each set of prints.

2-5 Calculating SQF of photographs.

A Subjective Quality Factor (SQF) was developed as the result of a search for an objective figure of merit which could be easily calculated and directly measured in practice and which would correlate with subjective rank regardless of MTF form. The SQF merit function predicts image appearance linearly when the actions of the eye including the magnification of the image are taken into consideration. A linear relationship was developed between SQF and σ_D to predict the subjects averaged response for each set of prints. Image quality is related to both MTF and granularity. They act independently as when increase in granularity then we expect a loss in image quality and also when a loss of MTF we can expect a loss of image quality as well.

$$I.Q. = SQF - a\sigma_D \qquad (21)$$

A routine was written in Mathcad 4.0 and used to calculated SQF. Programs and calculations are shown on Appendix-4. An image quality assessment was performed by using SQF.

2-6 Calculating Information Capacity.

Information capacity of an emulation depends on the modulation transfer function (MTF) and the granularity of the emulsion. In this study MTF of each system was obtained first, then a linear relationship was developed between Information Theory and σ_D to predict the subjects averaged response for each set of prints.

$$I.Q. = a_o + b_o(IC)$$

A routine was written in Mathcad 4.0 and used to calculate Information Capacity. Programs and calculations are shown on Appendix-5. Information Theory was also used to predict image quality by calculating information capacity and taking granularity into consideration.

III. Results

3- 1 MTF of the final prints was calculated:

(1) All of the seven gray card photographs were scanned and digitized by using Crosfield Magnascan 636 reflection drum scanner. An edge trace was performed, and a scanning of 18 pixels / mm was used.

(2). MTF's of each print were calculated according to the following equations:

$$\ell(x) = \frac{\partial e(x)}{\partial x}$$

$$OTF(f) = \int_{-\infty}^{\infty} \ell(x) e^{i2\pi fx} \partial x$$

$$\sum_{n=1}^{n} \ell_{(n)} e^{i2\pi fn\Delta x} \Delta x$$

$$MTF(f) = |OTF(f)|$$

A routine was written in Mathcad 4.0 and used to do the calculation. The MTF's are as follows:

Figure 4 MTF of final print by using T-MAX 100 film w/ 25mm lens

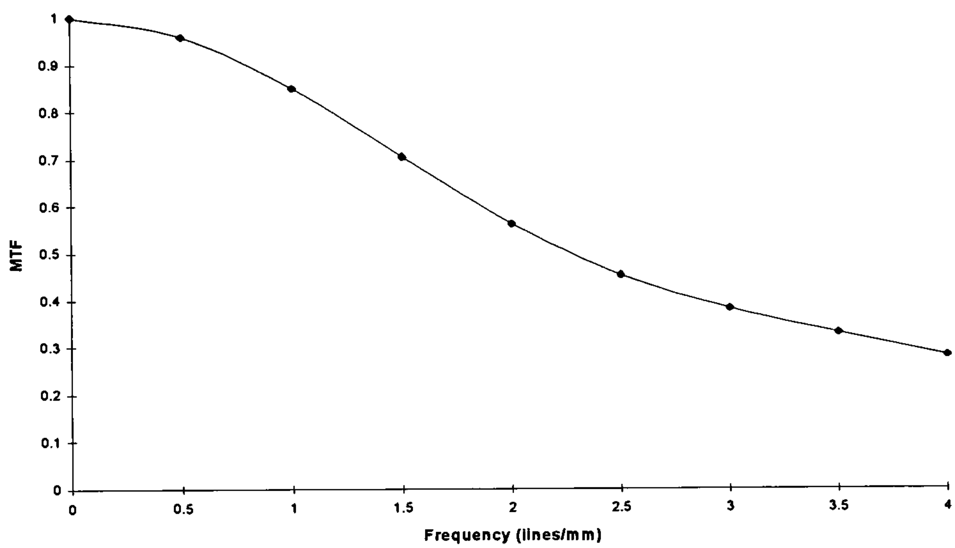


Figure 5 MTF of final print by using T-MAX 400 film w/25 mm lens

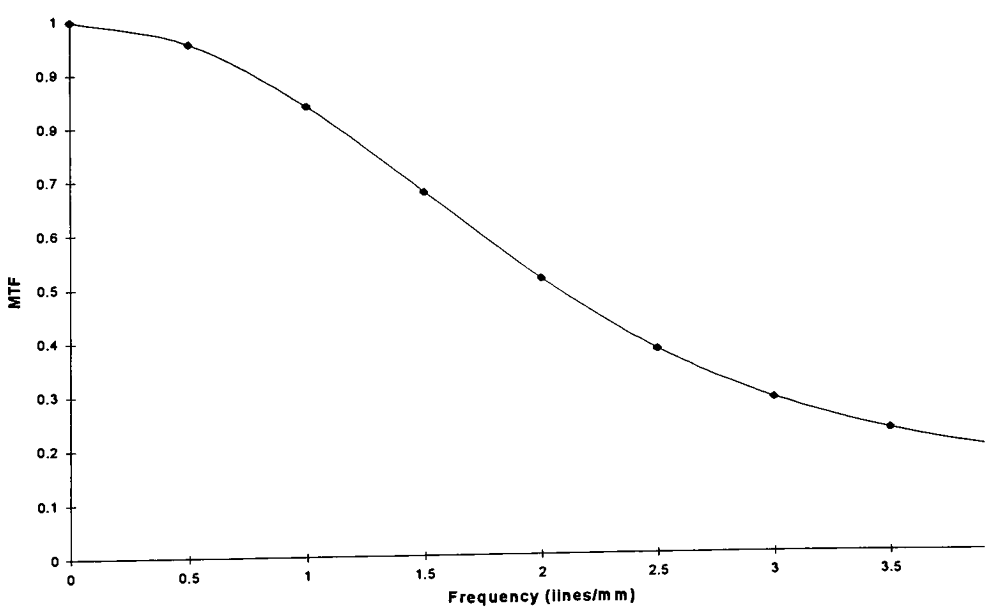


Figure 6 MTF of final print by using T-MAX 3200 film w/25 mm lens

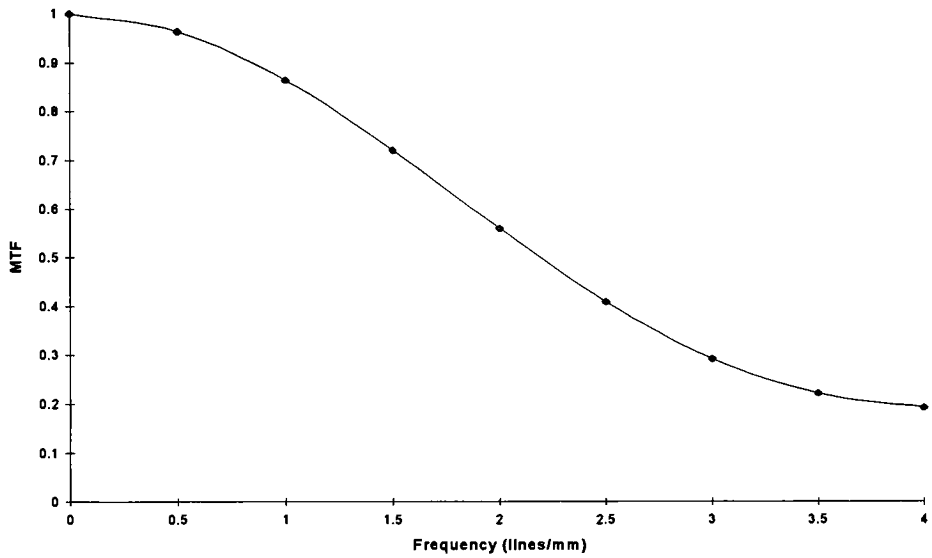


Figure 7 MTF of final print by using TRI-X 400 film w/25 mm lens

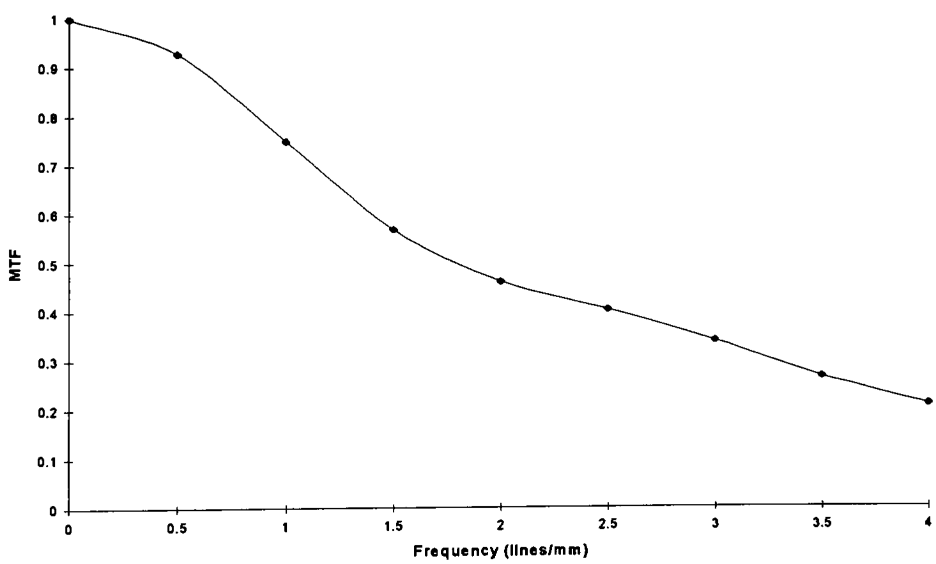


Figure 8 MTF of final print by using TRI-X 400 film w/ 50 mm lens

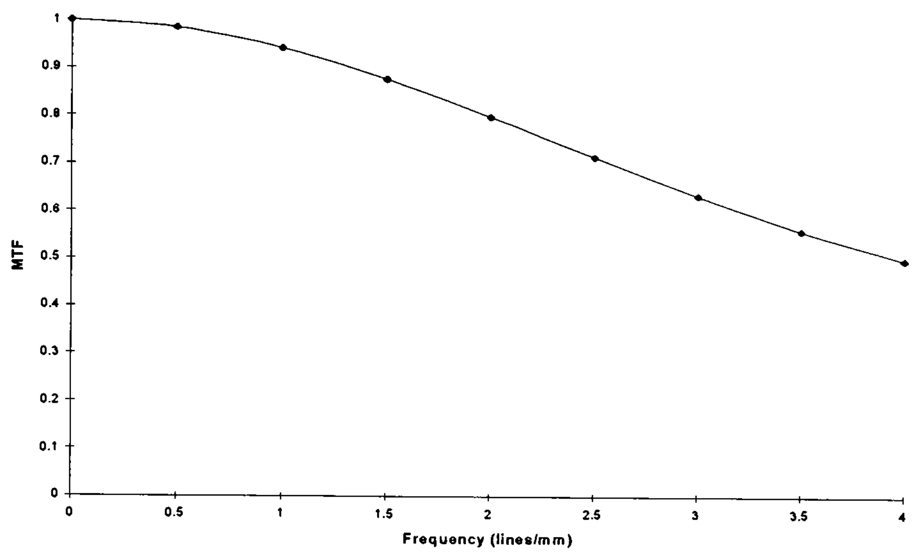


Figure 9 MTF of final print by using T-MAX 400 film w/ 50 mm lens

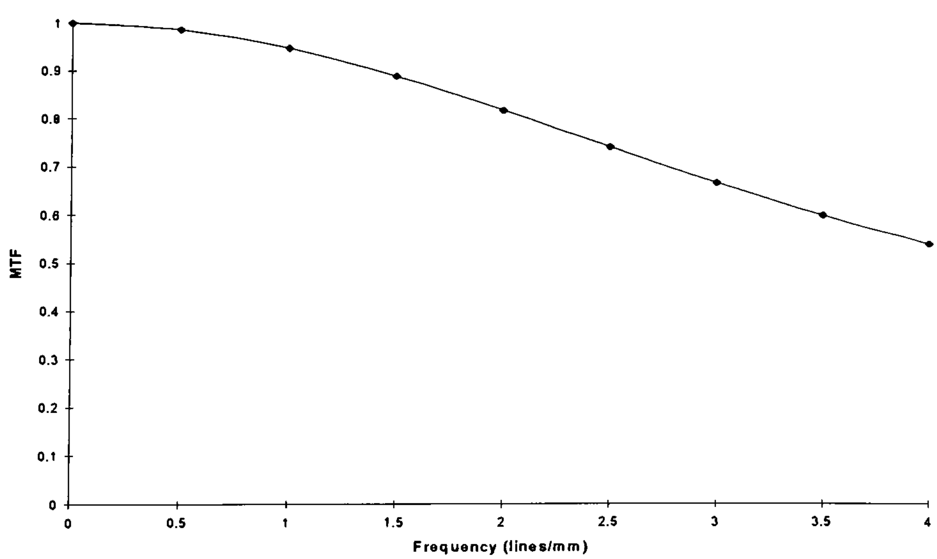
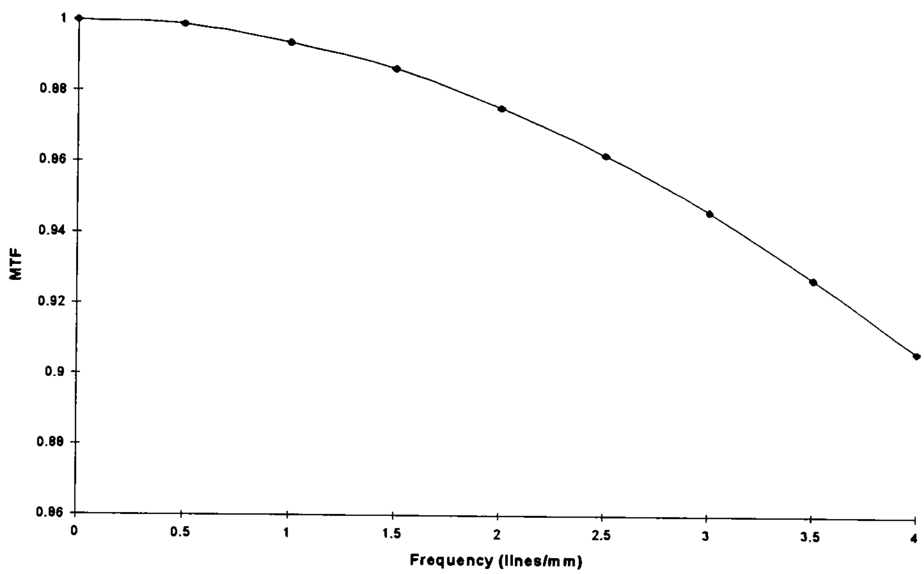


Figure 10 T-MAX 3200 film w/ 135 mm lens



3-2 Granularity analysis

Photoshop 4-5 was used to obtain the granularity data from the final prints. Therefore this measurement contain a systems level of MTF, including MTF of film, paper, lens and scanner used for measurement. One set of data was obtained with a low pass filter and the second set of data was obtained without a filter. The digital data were scaled as an integers between 0 and 255 and mean of 128 was used for calculation. Granularity readings from Photoshop 4-5 with and without the low pass filter are:

Table VII Granularity results

	T-MAX 100 25 mm	T-MAX 400 25 mm	T-MAX 3200 25 mm	TRI-X 400 25 mm	TRI-X 400 50 mm	T-MAX 400 50 mm	T--MAX 3200 135 mm
Print Granularity W/ filter	5.1	9.3	10.3	8.0	4.6	5.4	5.1
Print Granularity w/o	9.4	9.7	19.1	15.3	8.7	9.6	14.6

By using equation:

$$G_{New} = \left(\log \frac{Noise(\sigma)}{White} \right) + \log 2$$

we have new granularity data as:

Table VIII Calculated Granularity results

	T-MAX 100 25 mm	T-MAX 400 25 mm	T-MAX 3200 25 mm	TRI-X 400 25 mm	TRI-X 400 50 mm	T-MAX 400 50 mm	T--MAX 3200 135 mm
Print Granularity W/ filter	0.0183	0.0322	0.0353	0.028	0.017	0.0196	0.0187
print Granularity w/o	0.0325	0.0334	0.0486	0.0507	0.0303	0.0331	0.0621

3-3 SQF of photographs

Image quality was determined by using the correlation of SQF & σ_{DF} subject data for each photograph.

(1). A routine was written in Mathcad 4.0 to calculate the SQF.

Table IX SQF results

	T-MAX 100 25 mm	T-MAX 400 25 mm	T-MAX 3200 25 mm	TRI-X 400 25 mm	TRI-X 400 50 mm	T-MAX 400 50 mm	T--MAX 3200 135 mm
SQF	0.57	0.51	0.48	0.54	0.77	0.79	0.97

(2) The following equation was used to take granularity into consideration:

$$\sum_{n=1}^{n}\left(R_{(prediction)}(N) - aSQF(N) - b\sigma_0(N)\right)^2 = 0$$

a=1 and b=-3.6

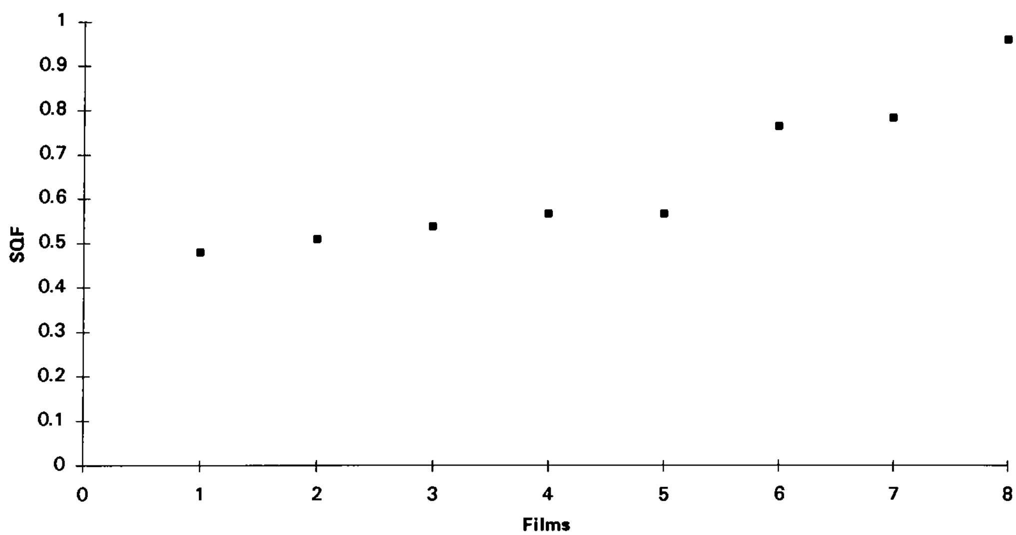
then

R(prediction) = SQF - 3.6G

Table X Results of prediction by using SQF

	T-MAX 100 25 mm	T-MAX 400 25 mm	T-MAX 3200 25 mm	TRI-X 400 25 mm	TRI-X 400 50 mm	T-MAX 400 50 mm	T–MAX 3200 135 mm
$R_{(prediction)}$	0.51	0.40	0.36	0.44	0.71	0.72	0.91
$R_{(measured)}$	0.57	0.51	0.48	0.54	0.77	0.79	0.97

Fig 11 SQF results



3-4 Information Capacity of photographs

Image quality was obtain by using Information Theory for each print:

(1) A routine was written in Mathcad 4.0 to calculate information capacity with the granularity taken into consideration. The results are as follows:

Table XI Information Theory results

	T-MAX 100 25 mm	T-MAX 400 25 mm	T-MAX 3200 25 mm	TRI-X 400 25 mm	TRI-X 400 50 mm	T-MAX 400 50 mm	T–MAX 3200 135 mm
I.C.	30.9	30.0	24.8	31.1	47.1	63.2	63.5

(2) The following equation was used to take granularity into consideration:

$$R_{(prediction)} = 0.0884+0.0119*\mathrm{IC}$$

Table XII Results of prediction by using Information Theory

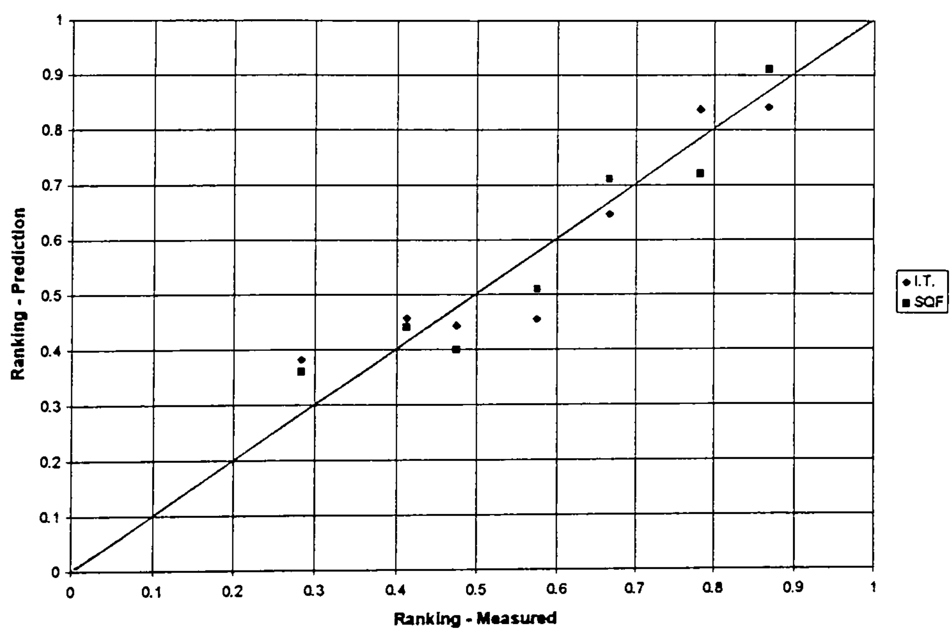
	T-MAX 100 25 mm	T-MAX 400 25 mm	T-MAX 3200 25 mm	TRI-X 400 25 mm	TRI-X 400 50 mm	T-MAX 400 50 mm	T–MAX 3200 135 mm
$R_{(prediction)}$	0.46	0.44	0.38	0.46	0.65	0.84	0.84
$R_{(measured)}$	0.57	0.51	0.48	0.54	0.77	0.79	0.97

IV DISCUSSION

4-1 Comparison of results using SQF and Information Theory.

Judging the results from Figure (12) we can say both SQF and Information Theory can produce very reasonable results. But overall the SQF does a better job of predicting image quality.

Figure 12 I.T. and SQF ranking prediction



The prediction of the image quality Vs measured granularity (σ_D):

Is Image Quality $\alpha \ \frac{1}{\sqrt{ASA}}$?

(a) When constant flux is used for exposure, the fast film has better image quality.

It is because the gain in MTF more than offsets the grain effects; also, because the fast films are usually sensitized better.

(b) Under normal exposure the slower film has better image quality.

Table XIII Summary of the results:

	T-MAX 100 25 mm	T-MAX 400 25 mm	T-MAX 3200 25 mm	TRI-X 400 25 mm	TRI-X 400 50 mm	T-MAX 400 50 mm	T--MAX 3200 135 mm
SQF	0.57	0.51	0.48	0.54	0.77	0.79	0.97
Information Cap.	10.16	9.98	10.55	9.8	15.21	21.73	27.72
Granularity w/ fil.	5.1	9.3	10.3	8.0	4.6	5.4	5.1
Granularity w/o	9.4	9.7	19.1	15.3	8.7	9.6	14.6
$R_{(prediction/SQF)}$	0.51	0.40	0.36	0.44	0.71	0.72	0.91
$R_{(prediction/I.T.)}$	0.46	0.44	0.38	0.46	0.65	0.84	0.84

Note:

(1) Constant flux condition:

G5: TRI-X 400 film / 50 mm lens

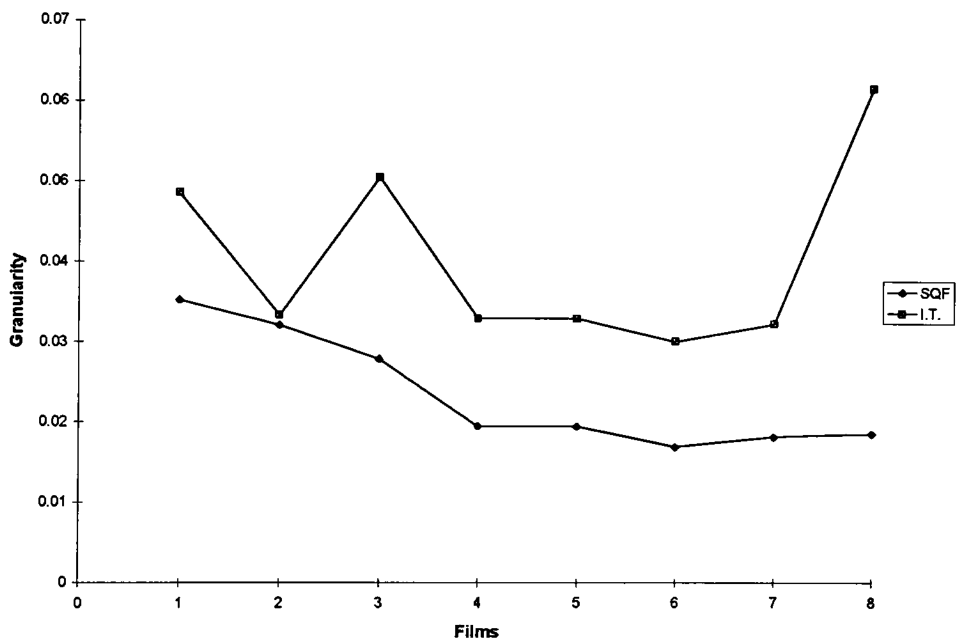
G6: T-MAX 400 film / 50 mm lens

(2) Normal exposure condition:

G2: T-MAX 400 film / 25 mm lens

G4: TRI-X 400 film / 25 mm lens

Figure 13 Comparison of granularity by using I. T. and SQF



Photoshop 4-5 was used to obtain the granularity data from the final prints. Therefore this measurement contain a systems level of MTF, including MTF of film, paper, lens and scanner used for measurement. One set of data was obtained with a low pass filter and the second set of data was obtained without a filter. The digital data were scaled as integers between 0 and 255 and a mean of 128 was used for the calculation. When we compare the granularity on each photograph by using SQF and Information Theory, we reach the following conclusions :

(a) When SQF is used for prediction:

Under constant flux the granularity in the print shows no big changes, but under normal exposure σ_D varies in proportion to the granularity.

(b) When Information Theory is used for prediction:

From Figure (13), it is obvious that it is very difficult to predict granularity by using Information Theory.

(c) The reason that SQF can predict film granularity is because SQF uses a low pass filter to simulate the human visual system and Information Theory does not.

(d) From this project we learn that when a fixed amount of photon flux and a fixed print size are used it is better to use a fast film. In the other words, under normal conditions, a slower film would be a better choice.

4-2 Results on T-MAX 400, and TRI-X 400 films

Compared with TRI-X 400, T-MAX 400 film is a newer product from Eastman Kodak Company. In this study we used both SQF and Information Theory to predict image quality, and to study the differences between these two films.

(a) Under constant flux condition:

The scanning was done from the final prints in this project. Therefore this measurement contain a systems level of MTF, including MTF of film, paper, lens and scanner used for measurement. According to the results from this project and by using the data in table XIII, when under constant flux it is clear that either with or without a filter for measurement the granularity of T-MAX 400 film is smaller than TRI-X 400 film. In the other words, the T-MAX 400 film is a finer film when compared to TRI-X 400 film.

(b) Under normal exposure condition:

By using the same Table XIII, under normal exposure, the result of granularity without using a filter it is obvious that the T-MAX 400 film has finer grain, when compared to TRI-X 400 film. When the filter is used, TRI-X 400 film has a granularity of 8.0 Vs 9.3 for T-MAX 400. It is possible that this is caused by the filter used in the system or the truncation of data during the scanning process. Possibly the photographic paper used is a cause.

(c) We can make a brief conclusion for this project as: When the print size is fixed and a fixed amount of photons were used in a system, it is better to use a fast film.

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VI APPENDICES

APPENDIX - 1

The followings are subjective ratings of 21 photographs from 33 different viewers.

Data:

The abbreviations are as follow:

Gray Card: G	Egg: E	Flower: F
T-MAX100 / 25 mm: 1	T-MAX 400 / 25 mm: 2	T-MAX 3200 / 25 mm: 3
TRI-X 400 / 25 mm: 4	TRI-X 400 / 50 mm: 5	T-MAX 400 / 50 mm: 6
T-MAX 3200 / 135 mm: 7		

	G1	G2	G3	G4	G5	G6	G7	E1	E2	E3	E4	E5	E6	E7	F1	F2	F3	F4	F5	F6	F7
Viewer #1	2	3	4	4	2	2	2	3	4	5	4	3	2	2	3	4	5	5	3	3	1
Viewer #2	3	4	4	4	3	2	2	4	3	3	4	2	3	2	4	4	4	4	3	4	2
Viewer #3	2	3	3	4	3	2	3	4	4	4	4	3	3	3	4	4	4	4	3	4	2
Viewer #4	3	4	5	3	4	3	2	3	4	5	4	3	3	1	3	4	5	4	3	3	2
Viewer #5	3	4	5	3	4	1	1	4	3	5	4	2	2	2	2	4	4	4	3	3	2
Viewer #6	3	4	4	3	3	1	1	3	4	5	5	3	1	2	2	3	4	4	2	3	1
Viewer #7	3	3	3	4	1	1	1	5	5	5	5	4	2	1	4	5	5	5	2	3	1
Viewer #8	2	2	3	2	1	2	1	2	2	3	3	2	1	1	2	3	4	2	1	2	1
Viewer #9	2	3	7	6	3	2	1	4	6	7	5	2	3	1	3	6	7	7	4	2	1

Viewer #10	4	6	7	6	4	2	1	5	5	7	7	5	2	1	4	7	7	5	3	3	2
Viewer #11	2	2	2	2	4	2	2	3	4	3	2	2	2	2	3	3	3	4	3	4	2
Viewer #12	4	6	6	6	4	4	3	5	6	5	6	5	3	2	3	7	7	6	6	7	3
Viewer #13	4	4	7	6	3	3	3	6	6	7	7	5	3	2	4	6	7	7	5	3	3
Viewer #14	5	4	7	6	3	1	2	5	7	6	4	3	1	2	5	5	7	6	3	2	1
Viewer #15	4	5	7	6	3	2	1	4	5	3	6	3	2	1	3	5	7	6	4	2	1
Viewer #16	4	4	5	4	2	2	2	3	5	5	4	2	3	2	4	6	5	6	4	3	3
Viewer #17	3	4	6	4	3	3	2	5	5	6	5	4	3	2	4	4	5	6	3	3	2
Viewer #18	5	6	5	4	4	4	2	5	6	6	6	5	5	4	5	6	6	6	4	4	3
Viewer #19	4	4	6	5	3	1	1	4	6	7	6	4	3	1	4	5	6	5	2	4	1
Viewer #20	5	6	6	6	4	4	2	5	6	6	6	5	5	3	5	5	6	5	4	4	2
Viewer #21	4	3	7	4	2	2	1	4	5	7	6	2	2	1	2	3	6	3	2	4	3
Viewer #22	6	6	7	5	4	4	3	6	6	6	7	4	4	3	5	5	7	7	4	4	3
Viewer #23	4	5	5	4	3	2	2	4	6	7	5	4	2	1	4	5	6	7	2	2	1
Viewer #24	3	4	5	5	2	1	1	2	4	5	5	2	1	2	4	4	5	4	3	4	2
Viewer #25	3	4	4	4	2	3	2	4	4	5	5	4	3	3	3	3	5	4	3	2	2
Viewer #26	3	4	5	5	3	3	2	3	4	5	4	3	2	2	3	4	5	4	3	4	2
Viewer #27	4	5	6	6	4	2	1	4	4	6	5	4	2	2	3	5	6	5	4	2	1
Viewer #28	4	5	6	4	4	3	1	4	5	6	5	5	1	1	4	5	6	5	4	3	2
Viewer #29	4	4	5	5	3	3	1	3	5	5	5	3	2	2	3	3	4	4	2	3	2
Viewer #30	5	5	5	4	3	2	3	5	3	4	4	3	2	2	4	4	5	5	3	3	2
Viewer #31	3	4	6	5	2	2	3	4	4	6	5	4	2	2	5	5	6	6	5	4	2
Viewer #32	3	3	6	5	3	2	2	2	5	6	6	2	2	2	2	3	4	4	2	2	3
Viewer #33	4	4	6	5	3	3	2	4	5	6	5	4	3	2	3	4	5	5	3	3	2

APPENDIX - 2

The following Line Spread Function data was obtained by using Photoshop 2-5.

(a) T-MAX100 / 25 mm:

Pixel #	Edge Reflectance	Line Spread Function
1	231	
2	230	1
3	228	2
4	226	2
5	221	5
6	213	8
7	200	13
8	184	16
9	162	22
10	144	18
11	130	14
12	124	6
13	119	5
14	117	2
15	114	3
16	111	3
17	109	2

(b) T-MAX 400 / 25 mm:

Pixel #	Edge Reflectance	Line Spread Function
1	227	
2	226	1
3	226	0
4	223	3
5	220	3
6	215	5
7	209	6
8	200	9
9	187	13
10	172	15
11	154	18
12	137	17
13	128	9
14	121	7
15	116	5
16	113	3
17	111	2
18	108	3
19	107	1
20	104	3

(c) T-MAX 3200 / 25 mm:

Pixel #	Edge Reflectance	Line Spread Function
1	225	
2	224	1
3	223	1
4	221	2
5	218	3
6	213	5
7	206	6
8	196	10
9	180	16
10	159	21
11	137	22
12	121	16
13	110	11
14	103	7
15	98	5
16	96	2
17	92	4
18	88	4
19	85	3
20	82	3
21	81	1

(d) TRI-X 400 / 25 mm:

Pixel #	Edge Reflectance	Line Spread Function
1	225	
2	221	4
3	218	3
4	215	3
5	207	8
6	194	13
7	178	16
8	158	20
9	139	19
10	129	10
11	119	10
12	116	3
13	109	7
14	104	5
15	100	4
16	99	1

(e) TRI-X 400 / 50 mm

Pixel #	Edge Reflectance	Line Spread Function
1	223	
2	222	1
3	220	2
4	218	2
5	212	6
6	194	18
7	162	32
8	129	33
9	109	20
10	101	8
11	97	4
12	95	2
13	93	2
14	91	2

(f) T-MAX 400 / 50 mm:

Pixel #	Edge Reflectance	Line Spread Function
1	229	
2	227	2
3	225	2
4	215	10
5	186	29
6	141	45
7	119	22
8	112	7
9	104	8
10	97	7
11	97	0
12	96	1
13	94	2

(g) T-MAX 3200 / 135 mm

Pixel #	Edge Reflectance	Line Spread Function
1	232	
2	233	-1
3	222	11
4	150	72
5	89	61
6	88	1

Written Mathcad 4.0 program and results for Information MTFs

(a) T-MAX100 / 25 mm:

$i := 0 .. 71$

$x_i := 0$

$x_1 := .79$

$x_2 := 1.59$

$x_3 := 1.59$

$x_4 := 3.97$

$x_5 := 6.35$

$x_6 := 10.32$

$x_7 := 12.7$

$x_8 := 17.46$

$x_9 := 14.29$

$x_{10} := 11.11$

$x_{11} := 4.76$

$x_{12} := 3.97$

$x_{13} := 1.59$

$x_{14} := 2.38$

$x_{15} := 2.38$

$x_{16} := 1.59$

$x_{17} := 1.59$

$x_{18} := 1.59$

$x_{19} := 0$

$x_{20} := 0$

$x_{21} := 0$

$x_{22} := 0$

$x_{23} := 0$

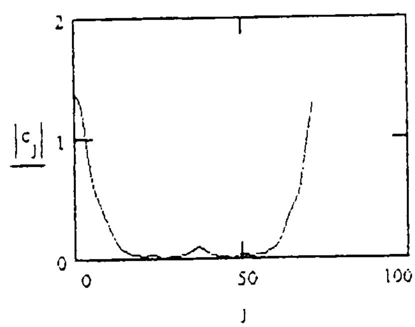
$x_{24} := 0$

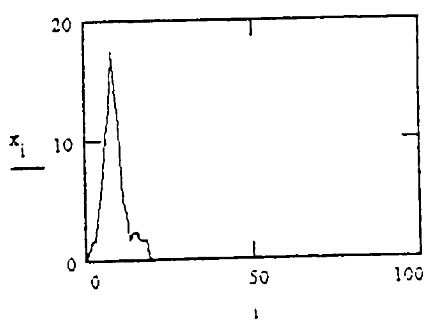
$c := \mathrm{CFFT}(x)$

$N := \mathrm{last}(c) \quad N = 71$
$j := 0 .. N$

$\lvert c_j \rvert$	$\dfrac{\lvert c_j \rvert}{1.389}$	x_i
1.389	1	0
1.334	0.96	0.79
1.184	0.852	1.59
0.984	0.708	1.59
0.787	0.566	3.97
0.635	0.457	6.35
0.534	0.385	10.32
0.462	0.333	12.7
0.396	0.285	17.46
0.327	0.235	14.29
0.256	0.184	11.11
0.19	0.137	4.76
0.135	0.098	3.97
0.098	0.071	1.59
0.076	0.055	2.38
0.063	0.045	2.38
0.055	0.04	1.59
0.052	0.037	1.59
0.044	0.032	1.59
0.031	0.023	0
0.032	0.023	0
0.048	0.035	0
0.057	0.041	0
0.051	0.037	0
0.033	0.024	0
0.017	0.012	0
0.022	0.016	0
0.028	0.02	0
0.028	0.02	0
0.029	0.021	0
0.036	0.026	0
0.045	0.033	0
0.056	0.041	0
0.072	0.052	0
0.09	0.065	0
0.105	0.075	0
0.11	0.079	0
0.105	0.075	0
0.09	0.065	0
0.072	0.052	0
0.056	0.041	0
0.045	0.033	0
0.036	0.026	0
0.029	0.021	0
0.028	0.02	0
0.028	0.02	0
0.022	0.016	0

0.017	0.012	0
0.033	0.024	0
0.051	0.037	0





(b) T-MAX400 / 25 mm:

$i := 0 .. 71$

$x_i := 0$

$x_1 := 2.44$

$x_2 := 2.44$

$x_3 := 4.07$

$x_4 := 4.88$

$x_5 := 7.32$

$x_6 := 10.57$

$x_7 := 12.2$

$x_8 := 14.63$

$x_9 := 13.82$

$x_{10} := 7.32$

$x_{11} := 5.69$

$x_{12} := 4.07$

$x_{13} := 2.44$

$x_{14} := 1.63$

$x_{15} := 2.44$

$x_{16} := 0.81$

$x_{17} := 2.44$

$x_{18} := 0$

$x_{19} := 0$

$x_{20} := 0$

$x_{21} := 0$

$x_{22} := 0$

$x_{23} := 0$

$x_{24} := 0$

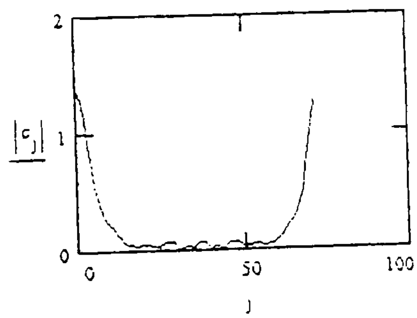
$c := \mathrm{CFFT}(x)$

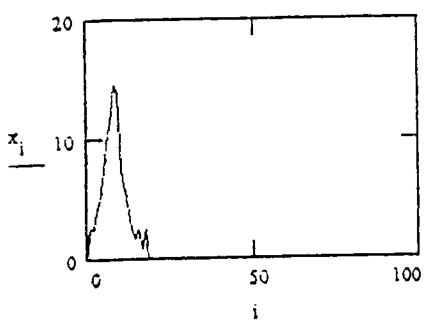
$N := \mathrm{last}(c) \quad N = 71$

$j := 0..N$

$\left\|c_j\right\|$	$\dfrac{\left\|c_j\right\|}{1.378}$	x_i
1.378	1	0
1.318	0.957	2.44
1.156	0.839	2.44
0.935	0.678	4.07
0.709	0.515	4.88
0.524	0.381	7.32
0.396	0.288	10.57
0.314	0.228	12.2
0.261	0.189	14.63
0.226	0.164	13.82
0.195	0.142	7.32
0.157	0.114	5.69
0.115	0.083	4.07
0.083	0.06	2.44
0.071	0.051	1.63
0.062	0.045	2.44
0.051	0.037	0.81
0.053	0.038	2.44
0.066	0.048	0
0.07	0.051	0
0.062	0.045	0
0.053	0.039	0
0.052	0.038	0
0.055	0.04	0
0.063	0.046	0
0.078	0.056	0
0.09	0.066	0
0.087	0.063	0
0.061	0.044	0
0.022	0.016	0
0.027	0.02	0
0.051	0.037	0
0.049	0.036	0
0.03	0.022	0
0.044	0.032	0
0.077	0.056	0
0.09	0.066	0
0.077	0.056	0
0.044	0.032	0
0.03	0.022	0
0.049	0.036	0
0.051	0.037	0
0.027	0.02	0
0.022	0.016	0
0.061	0.044	0
0.087	0.063	0
0.09	0.066	0

0.078	0.056	0
0.063	0.046	0
0.055	0.04	0





(c) T-MAX3200 / 25 mm:

$i := 0 .. 41$

$x_i := 0$

$x_1 := 0.66$

$x_2 := 0.66$

$x_3 = 1.32$

$x_4 = 1.99$

$x_5 := 3.31$

$x_6 = 3.97$

$x_7 := 6.62$

$x_8 := 10.6$

$x_9 := 13.91$

$x_{10} := 14.57$

$x_{11} := 10.6$

$x_{12} := 7.28$

$x_{13} := 4.64$

$x_{14} := 3.31$

$x_{15} := 1.32$

$x_{16} := 2.64$

$x_{17} := 2.64$

$x_{18} := 1.99$

$x_{19} := 1.99$

$x_{20} := 0.66$

$x_{21} := 0.66$

$x_{22} := 1.99$

$x_{23} := 1.32$

$x_{24} = 1.32$

$c := \mathrm{CFFT}(x)$

$N := \mathrm{last}(c) \quad N = 71$

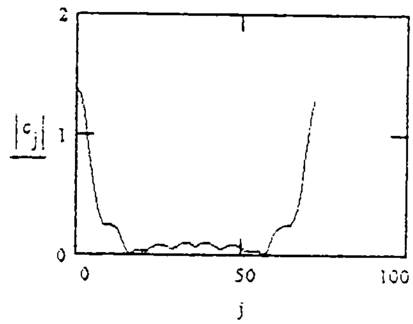
$j := 0 .. N$

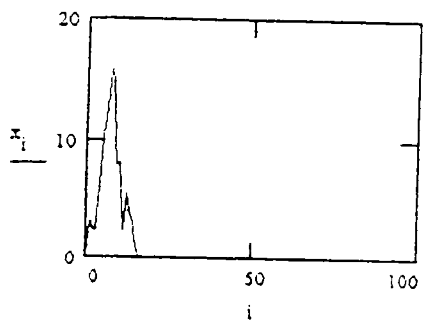
$\lvert c_j \rvert$	$\frac{\lvert c_j \rvert}{1.389}$	x_i
1.389	1	0
1.34	0.965	3.17
1.203	0.866	2.38
1.004	0.723	2.38
0.781	0.562	6.35
0.572	0.412	10.32
0.41	0.295	12.7
0.312	0.224	15.87
0.27	0.194	15.08
0.26	0.187	7.94
0.258	0.186	7.94
0.251	0.18	2.38
0.226	0.163	5.56
0.181	0.131	3.97
0.121	0.087	3.17
0.057	0.041	0.79
0.015	0.011	0
0.042	0.03	0
0.056	0.041	0
0.053	0.038	0
0.047	0.034	0
0.054	0.039	0
0.071	0.051	0
0.087	0.062	0
0.095	0.069	0
0.098	0.07	0
0.093	0.067	0
0.082	0.059	0
0.068	0.049	0
0.063	0.045	0
0.077	0.056	0
0.1	0.072	0
0.118	0.085	0
0.122	0.088	0
0.113	0.081	0
0.097	0.07	0
0.088	0.064	0
0.097	0.07	0
0.113	0.081	0
0.122	0.088	0
0.118	0.085	0
0.1	0.072	0
0.077	0.056	0
0.063	0.045	0
0.068	0.049	0
0.082	0.059	0
0.093		

0.098
0.095
0.087

0.07
0.069
0.062

0
0
0





(d) TRI-X400 / 25 mm:

$i := 0 .. 71$

$x_i := 0$

$x_1 := 3.17$

$x_2 := 2.38$

$x_3 := 2.38$

$x_4 := 6.35$

$x_5 := 10.32$

$x_6 := 12.7$

$x_7 := 15.87$

$x_8 := 15.08$

$x_9 := 7.94$

$x_{10} := 7.94$

$x_{11} := 2.38$

$x_{12} := 5.56$

$x_{13} := 3.97$

$x_{14} := 3.17$

$x_{15} := 0.79$

$x_{16} := 0$

$x_{17} := 0$

$x_{18} := 0$

$x_{19} := 0$

$x_{20} := 0$

$x_{21} := 0$

$x_{22} := 0$

$x_{23} := 0$

$x_{24} := 0$

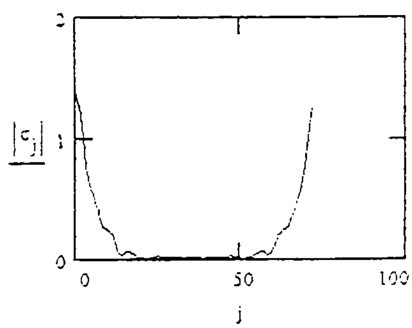
$c := \mathrm{CFFT}(x)$

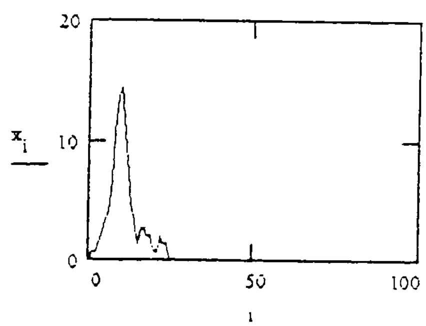
$N := \mathrm{last}(c) \quad N = 71$

$j := 0..N$

$\lvert c_j \rvert$	$\frac{\lvert c_j \rvert}{1.388}$	x_i
1.388	1	0
1.287	0.927	0.66
1.04	0.749	0.66
0.788	0.568	1.32
0.639	0.461	1.99
0.56	0.404	3.31
0.472	0.34	3.97
0.369	0.266	6.62
0.29	0.209	10.6
0.262	0.189	13.91
0.25	0.18	14.57
0.211	0.152	10.6
0.138	0.099	7.28
0.059	0.042	4.64
0.044	0.032	3.31
0.079	0.057	1.32
0.089	0.064	2.64
0.073	0.052	2.64
0.046	0.033	1.99
0.033	0.023	1.99
0.031	0.022	0.66
0.025	0.018	0.66
0.024	0.017	1.99
0.032	0.023	1.32
0.04	0.029	1.32
0.042	0.03	0
0.037	0.027	0
0.032	0.023	0
0.03	0.022	0
0.03	0.022	0
0.037	0.027	0
0.04	0.029	0
0.028	0.02	0
0.021	0.015	0
0.034	0.025	0
0.034	0.025	0
0.028	0.02	0
0.034	0.025	0
0.034	0.025	0
0.021	0.015	0
0.028	0.02	0
0.04	0.029	0
0.037	0.027	0
0.03	0.022	0
0.03	0.022	0
0.032	0.023	0
0.037	0.027	0

0.042	0.03	0
0.04	0.029	0
0.032	0.023	0





(e) TRI-X400 / 50 mm:

$i = 0 .. 71$

$x_i = 0$

$x_1 := 0.76$

$x_2 = 1.52$

$x_3 := 1.52$

$x_4 = 4.55$

$x_5 = 13.04$

$x_6 = 24.24$

$x_7 := 25.0$

$x_8 = 15.15$

$x_9 := 6.06$

$x_{10} := 3.03$

$x_{11} := 1.52$

$x_{12} := 1.52$

$x_{13} := 1.52$

$x_{14} := 0$

$x_{15} := 0$

$x_{16} = 0$

$x_{17} := 0$

$x_{18} := 0$

$x_{19} := 0$

$x_{20} = 0$

$x_{21} := 0$

$x_{22} := 0$

$x_{23} := 0$

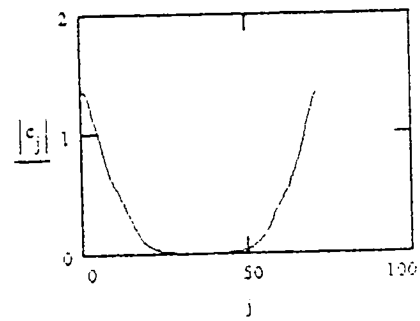
$x_{24} := 0$

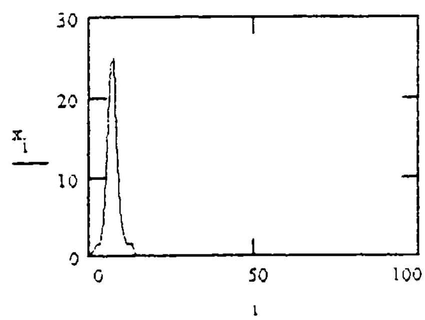
$c := CFFT(x)$

$N := last(c) \quad N = 71$
$j := 0..N$

$\lvert c_j \rvert$	$\frac{\lvert c_j \rvert}{1.389}$	x_i
1.389	1	0
1.369	0.986	0.76
1.311	0.944	1.52
1.222	0.88	1.52
1.114	0.802	4.55
0.998	0.719	13.64
0.886	0.638	24.24
0.785	0.565	25
0.699	0.503	15.15
0.627	0.452	6.06
0.566	0.408	3.03
0.511	0.368	1.52
0.457	0.329	1.52
0.4	0.288	1.52
0.342	0.246	0
0.282	0.203	0
0.225	0.162	0
0.175	0.126	0
0.135	0.097	0
0.106	0.076	0
0.085	0.061	0
0.069	0.05	0
0.055	0.039	0
0.043	0.031	0
0.036	0.026	0
0.033	0.024	0
0.03	0.022	0
0.025	0.018	0
0.018	0.013	0
0.012	0.008	0
0.009	0.007	0
0.011	0.008	0
0.011	0.008	0
0.01	0.007	0
0.007	0.005	0
0.004	0.003	0
$1.389 \cdot 10^{-4}$	$9.999 \cdot 10^{-5}$	0
0.004	0.003	0
0.007	0.005	0
0.01	0.007	0
0.011	0.008	0
0.011	0.008	0
0.009	0.007	0
0.012	0.008	0
0.018	0.013	0
0.025	0.018	0
0.03		

	0.022	
0.033	0.024	0
0.036	0.026	0
0.043	0.031	0





(f) T-MAX400 / 50 mm:

$i := 0 .. 71$

$x_i := 0$

$x_1 := 1.48$

$x_2 := 1.48$

$x_3 := 7.41$

$x_4 := 21.48$

$x_5 := 33.33$

$x_6 := 16.3$

$x_7 := 5.19$

$x_8 := 5.93$

$x_9 := 5.19$

$x_{10} := 0$

$x_{11} := 0.74$

$x_{12} := 1.48$

$x_{13} := 0$

$x_{14} := 0$

$x_{15} := 0$

$x_{16} := 0$

$x_{17} := 0$

$x_{18} := 0$

$x_{19} := 0$

$x_{20} := 0$

$x_{21} := 0$

$x_{22} := 0$

$x_{23} := 0$

$x_{.} := 0$

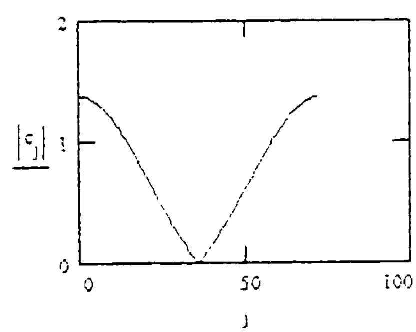
$c := CFFT(x)$

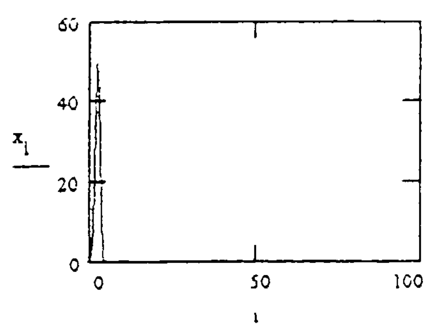
$N := last(c) \quad N = 71$

$j := 0..N$

$\lvert c_j \rvert$	$\dfrac{\lvert c_j \rvert}{1.389}$	x_i
1.389	1	0
1.387	0.999	7.59
1.381	0.994	49.66
1.37	0.987	42.07
1.356	0.976	0.69
1.338	0.963	0
1.315	0.947	0
1.29	0.928	0
1.26	0.907	0
1.228	0.884	0
1.192	0.858	0
1.154	0.831	0
1.113	0.802	0
1.07	0.771	0
1.025	0.738	0
0.979	0.705	0
0.931	0.67	0
0.882	0.635	0
0.832	0.599	0
0.781	0.563	0
0.731	0.526	0
0.68	0.49	0
0.63	0.453	0
0.579	0.417	0
0.53	0.382	0
0.481	0.346	0
0.433	0.312	0
0.386	0.278	0
0.34	0.245	0
0.295	0.212	0
0.251	0.181	0
0.207	0.149	0
0.165	0.119	0
0.123	0.089	0
0.082	0.059	0
0.042	0.03	0
0.01	0.007	0
0.042	0.03	0
0.082	0.059	0
0.123	0.089	0
0.165	0.119	0
0.207	0.149	0
0.251	0.181	0
0.295	0.212	0
0.34	0.245	0

0.481	0.346	0
0.53	0.382	0
0.579	0.417	0





(g) T-MAX3200 / 135 mm:

$i := 0 .. 71$

$x_i := 0$

$x_1 := 7.59$

$x_2 := 49.66$

$x_3 := 42.07$

$x_4 := 0.69$

$x_5 := 0$

$x_5 := 0$

$x_7 := 0$

$x_8 := 0$

$x_9 := 0$

$x_{10} := 0$

$x_{11} := 0$

$x_{12} := 0$

$x_{13} := 0$

$x_{14} := 0$

$x_{15} := 0$

$x_{16} := 0$

$x_{17} := 0$

$x_{18} := 0$

$x_{19} := 0$

$x_{20} := 0$

$x_{21} := 0$

$x_{22} := 0$

$x_{23} := 0$

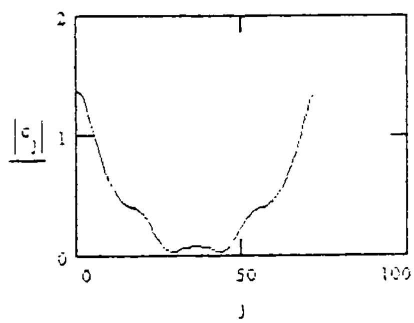
$x := 0$

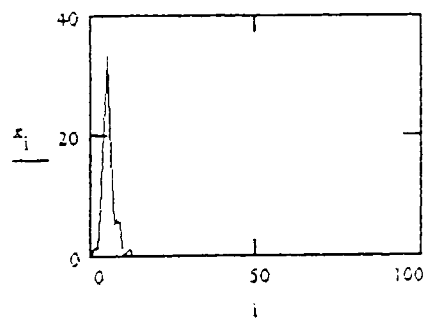
$c := CFFT(x)$

$N := last(c) \quad N = 71$
$j := 0..N$

$\lvert c_j \rvert$	$\frac{\lvert c_j \rvert}{1.389}$	x_i
1.389	1	0
1.371	0.987	1.48
1.318	0.949	1.48
1.238	0.891	7.41
1.14	0.82	21.48
1.034	0.744	33.33
0.931	0.67	16.3
0.837	0.603	5.19
0.756	0.544	5.93
0.686	0.494	5.19
0.625	0.45	0
0.57	0.411	0.74
0.522	0.376	1.48
0.482	0.347	0
0.451	0.325	0
0.431	0.31	0
0.419	0.302	0
0.411	0.296	0
0.401	0.289	0
0.384	0.277	0
0.357	0.257	0
0.32	0.23	0
0.274	0.197	0
0.223	0.16	0
0.172	0.124	0
0.125	0.09	0
0.087	0.063	0
0.061	0.044	0
0.048	0.034	0
0.048	0.035	0
0.057	0.041	0
0.069	0.049	0
0.079	0.057	0
0.087	0.062	0
0.091	0.065	0
0.092	0.066	0
0.093	0.067	0
0.092	0.066	0
0.091	0.065	0
0.087	0.062	0
0.079	0.057	0
0.069	0.049	0
0.057	0.041	0
0.048	0.035	0
0.048	0.034	0

0.125	0.09	0
0.172	0.124	0
0.223	0.16	0





APPENDIX - 4

Written Mathcad 4.0 program and results for SQFs

(a) T-MAX100 / 25 mm:

$i := 0..8 \quad j := 0..4$

$vx_i := i \cdot .25$

$vy_0 := 1$

$vy_1 := .96$

$vy_2 := .852$

$vy_3 := .708$

$vy_4 := .566$

$vy_5 := .457$

$vy_6 := .385$

$vy_7 := .333$

$vy_8 := .285$

$freq_0 := .5$

$freq_1 := .707$

$freq_2 := 1$

$freq_3 := 1.414$

$freq_4 := 2$

$mod(j) := linterp\left(vx, vy, freq_j\right)$

mod(j)

0.852
0.733
0.566
0.41
0.285

$$sqf := \frac{.5\cdot(mod(0) + mod(4)) + mod(1) + mod(2) + mod(3)}{4}$$

$sqf = 0.569$

(b) T-MAX400 / 25 mm:

$i := 0..8 \quad j := 0..4$

$vx_i := i \cdot .25$

$vy_0 := 1$

$vy_1 := .957$

$vy_2 := .839$

$vy_3 := .678$

$vy_4 := .515$

$vy_5 := .381$

$vy_6 := .288$

$vy_7 := .228$

$vy_8 := .189$

$freq_0 := .5$

$freq_1 := .707$

$freq_2 := 1$

$freq_3 := 1.414$

$freq_4 := 2$

$mod(j) := linterp\left(vx, vy, freq_j\right)$

mod(j)

0.839
0.706
0.515
0.32
0.189

$$sqf := \frac{.5 \cdot (mod(0) + mod(4)) + mod(1) + mod(2) + mod(3)}{4}$$

$sqf = 0.514$

(c) T-MAX3200 / 25 mm:

$i := 0..8 \quad j := 0..4$

$vx_i := i \cdot .25$

$vy_0 := 1$

$vy_1 := .927$

$vy_2 := .749$

$vy_3 := .568$

$vy_4 := .461$

$vy_5 := .404$

$vy_6 := .34$

$vy_7 := .266$

$vy_8 := .209$

$freq_0 := .5$

$freq_1 := .707$

$freq_2 := 1$

$freq_3 := 1.414$

$freq_4 := 2$

$mod(j) := linterp\left(vx, vy, freq_j\right)$

mod(j)
0.749
0.599
0.461
0.362
0.209

$$sqf := \frac{.5 \cdot (mod(0) + mod(4)) + mod(1) + mod(2) + mod(3)}{4}$$

$sqf = 0.475$

(d) TRI-X400 / 25 mm:

$i := 0..8 \quad j := 0..4$

$vx_i := i \cdot .25$

$vy_0 := 1$

$vy_1 := .965$

$vy_2 := .866$

$vy_3 := .723$

$vy_4 := .562$

$vy_5 := .412$

$vy_6 := .295$

$vy_7 := .224$

$vy_8 := .194$

$freq_0 := .5$

$freq_1 := .707$

$freq_2 := 1$

$freq_3 := 1.414$

$freq_4 := 2$

$mod(j) := linterp\left(vx, vy, freq_j\right)$

mod(j)

0.866
0.748
0.562
0.335
0.194

$$sqf := \frac{.5 \cdot (mod(0) + mod(4)) + mod(1) + mod(2) + mod(3)}{4}$$

$sqf = 0.544$

(e) TRI-X400 / 50 mm:

$i := 0..8 \quad j := 0..4$

$vx_i := i \cdot .25$

$vy_0 := 1$

$vy_1 := .986$

$vy_2 := .944$

$vy_3 := .88$

$vy_4 := .802$

$vy_5 := .719$

$vy_6 := .638$

$vy_7 := .565$

$vy_8 := .503$

$freq_0 := .5$

$freq_1 := .707$

$freq_2 := 1$

$freq_3 := 1.414$

$freq_4 := 2$

$mod(j) := linterp(vx, vy, freq_j)$

mod(j)

0.944
0.891
0.802
0.666
0.503

$$sqf := \frac{.5 \cdot (mod(0) + mod(4)) + mod(1) + mod(2) + mod(3)}{4}$$

$sqf = 0.771$

(f) T-MAX400 / 50 mm:

$i := 0..8 \quad j := 0..4$

$vx_i := i \cdot .25$

$vy_0 := 1$

$vy_1 := .987$

$vy_2 := .949$

$vy_3 := .891$

$vy_4 := .82$

$vy_5 := .744$

$vy_6 := .67$

$vy_7 := .603$

$vy_8 := .544$

$freq_0 := .5$

$freq_1 := .707$

$freq_2 := 1$

$freq_3 := 1.414$

$freq_4 := 2$

$mod(j) := linterp\left(vx, vy, freq_j\right)$

mod(j)

0.949
0.901
0.82
0.695
0.544

$$sqf := \frac{.5 \cdot (mod(0) + mod(4)) + mod(1) + mod(2) + mod(3)}{4}$$

$sqf = 0.791$

(g) T-MAX3200 / 135 mm:

$i := 0..8 \quad j := 0..4$

$vx_i := i \cdot .25$

$vy_0 := 1$

$vy_1 := .999$

$vy_2 := .994$

$vy_3 := .987$

$vy_4 := .976$

$vy_5 := .963$

$vy_6 := .947$

$vy_7 := .928$

$vy_8 := .907$

$freq_0 := .5$

$freq_1 := .707$

$freq_2 := 1$

$freq_3 := 1.414$

$freq_4 := 2$

$mod(j) := linterp\left(vx, vy, freq_j\right)$

mod(j)

0.994
0.988
0.976
0.953
0.907

$$sqf := \frac{.5 \cdot (mod(0) + mod(4)) + mod(1) + mod(2) + mod(3)}{4}$$

$sqf = 0.967$

APPENDIX - 5

Written Mathcad 4.0 program and Information Capacity results

(a) T-MAX100 / 25 mm:

:=

$mod_0 := 1$

$mod_1 := .96$

$mod_2 := .852$

$mod_3 := .708$

$mod_4 := .566$

$mod_5 := .457$

$mod_6 := .385$

$mod_7 := .333$

$mod_8 := .285$

$mod_9 := .235$

$mod_{10} := .184$

$mod_{11} := .137$

$mod_{12} := .098$

$mod_{13} := .071$

$mod_{14} := .055$

$mod_{15} := .045$

$mod_{16} := .04$

$mod_{17} := .037$

$mod_{18} := .032$

$mod_{19} := .023$

$mod_{20} := 0$

$mod_{21} := 0$

$mod_{22} := 0$

$mod_{23} := 0$

$mod_{24} := 0$

$mod_{25} := 0$

$mod_{26} := 0$

$mod_{27} := 0$

$mod_{28} := 0$

$mod_{29} := 0$

$mod_{30} := 0$

$mod_{31} := 0$

$mod_{32} := 0$

$mod_{33} := 0$

$mod_{34} := 0$

$mod_{35} := 0$

$mod_{36} := 0$

$noise := .0325$

$$C := \sum_{i=0}^{36} \log\left[1.0 - \left[\frac{(mod_i)}{noise}\right]^2\right] \qquad C = 30.85$$

(b) T-MAX400 / 25 mm:

$:=$

$mod_0 := 1$
$mod_1 := .957$
$mod_2 := .839$
$mod_3 := .678$
$mod_4 := .515$
$mod_5 := .381$
$mod_6 := .288$
$mod_7 := .228$
$mod_8 := .189$
$mod_9 := .164$
$mod_{10} := .142$
$mod_{11} := .114$
$mod_{12} := .083$
$mod_{13} := .06$
$mod_{14} := .051$
$mod_{15} := .045$
$mod_{16} := .037$
$mod_{17} := .038$
$mod_{18} := .048$
$mod_{19} := .051$
$mod_{20} := .045$
$mod_{21} := .039$
$mod_{22} := .038$
$mod_{23} := 0$
$mod_{24} := 0$
$mod_{25} := 0$
$mod_{26} := 0$
$mod_{27} := 0$
$mod_{28} := 0$
$mod_{29} := 0$
$mod_{30} := 0$

$mod_{31} := 0$
$mod_{32} := 0$
$mod_{33} := 0$
$mod_{34} := 0$
$mod_{35} := 0$
$mod_{36} := 0$
$noise := .0334$

$$C := \sum_{i=0}^{36} \log\left[1.0 + \left[\frac{(mod_i)}{noise}\right]^2\right] \qquad C = 29.991$$

(c) T-MAX3200 / 25 mm:

:=

$mod_0 := 1$

$mod_1 := .927$

$mod_2 := .749$

$mod_3 := .568$

$mod_4 := .461$

$mod_5 := .404$

$mod_6 := .34$

$mod_7 := .266$

$mod_8 := .209$

$mod_9 := .189$

$mod_{10} := .18$

$mod_{11} := .152$

$mod_{12} := .099$

$mod_{13} := .042$

$mod_{14} := .032$

$mod_{15} := .057$

$mod_{16} := .064$

$mod_{17} := .052$

$mod_{18} := .033$

$mod_{19} := .023$

$mod_{20} := .022$

$mod_{21} := .018$

$mod_{22} := .017$

$mod_{23} := .023$

$mod_{24} := .029$

$mod_{25} := .03$

$mod_{26} := .027$

$mod_{27} := .023$

$mod_{28} := .022$

$mod_{29} := .022$

$mod_{30} := 0$

$mod_{31} := 0$

$mod_{32} := 0$

$mod_{33} := 0$

$mod_{34} := 0$

$mod_{35} := 0$

$mod_{36} := 0$

noise = .0486

$$C := \sum_{i=0}^{36} \log\left[1.0 + \left[\frac{(mod_i)}{noise}\right]^2\right] \qquad C = 24.818$$

(d) TRI-X400 / 25 mm:

:=

$mod_0 := 1$

$mod_1 := .965$

$mod_2 := .866$

$mod_3 := .723$

$mod_4 := .562$

$mod_5 := 412$

$mod_6 := .295$

$mod_7 := .224$

$mod_8 := .194$

$mod_9 := .187$

$mod_{10} := .186$

$mod_{11} := .18$

$mod_{12} := .163$

$mod_{13} := .131$

$mod_{14} := .087$

$mod_{15} := .041$

$mod_{16} := .011$

$mod_{17} := .03$

$mod_{18} := 0$

$mod_{19} := 0$

$mod_{20} := 0$

$mod_{21} := 0$

$mod_{22} := 0$

$mod_{23} := 0$

$mod_{24} := 0$

$mod_{25} := 0$

$mod_{26} := 0$

$mod_{27} := 0$

$mod_{28} := 0$

$mod_{29} := 0$

$mod_{30} := 0$

$mod_{31} := 0$

$mod_{32} := 0$

$mod_{33} := 0$

$mod_{34} := 0$

$mod_{35} := 0$

$mod_{36} := 0$

$noise := .0303$

$$C := \sum_{i=0}^{36} \log\left[1.0 + \left[\frac{(mod_i)}{noise}\right]^2\right] \qquad C = 31.148$$

(e) TRI-X400 / 50 mm:

$mod_0 := 1$

$mod_1 := .986$

$mod_2 := .944$

$mod_3 := .88$

$mod_4 := .802$

$mod_5 := .719$

$mod_6 := .638$

$mod_7 := .565$

$mod_8 := .503$

$mod_9 := .452$

$mod_{10} := .408$

$mod_{11} := .368$

$mod_{12} := .329$

$mod_{13} := .288$

$mod_{14} := .246$

$mod_{15} := .203$

$mod_{16} := .162$

$mod_{17} := .126$

$mod_{18} := .097$

$mod_{19} := .076$

$mod_{20} := .061$

$mod_{21} := .05$

$mod_{22} := .039$

$mod_{23} := .031$

$mod_{24} := .026$

$mod_{25} := .024$

$mod_{26} := .022$

$mod_{27} := .018$

$mod_{28} := .013$

$mod_{29} := .008$

$mod_{30} := .007$

$mod_{31} := 0$

$mod_{32} := 0$

$mod_{33} := 0$

$mod_{34} := 0$

$mod_{35} := 0$

$mod_{36} := 0$

$noise := .0303$

$$C = \sum_{i=0}^{36} \log\left[1.0 - \left[\frac{(mod_i)}{noise}\right]^2\right] \qquad C = 47.06$$

(f) T-MAX400 / 50 mm:

:=

$mod_0 := 1$

$mod_1 := .987$

$mod_2 := 949$

$mod_3 := .891$

$mod_4 = .82$

$mod_5 := .744$

$mod_6 := .67$

$mod_7 := .603$

$mod_8 := .544$

$mod_9 := .494$

$mod_{10} := .45$

$mod_{11} := .411$

$mod_{12} := .376$

$mod_{13} := .347$

$mod_{14} := .325$

$mod_{15} := .31$

$mod_{16} := .302$

$mod_{17} := .296$

$mod_{18} := .289$

$mod_{19} := .277$

$mod_{20} := .257$

$mod_{21} := .23$

$mod_{22} := .197$

$mod_{23} := .16$

$mod_{24} := .124$

$mod_{25} := .09$

$mod_{26} := .063$

$mod_{27} := .044$

$mod_{28} := .034$

$mod_{29} := 0$

$mod_{30} := 0$

$mod_{31} := 0$

$mod_{32} := 0$

$mod_{33} := 0$

$mod_{34} := 0$

$mod_{35} := 0$

$mod_{36} := 0$

$noise := .0331$

$$C := \sum_{i=0}^{36} \log\left[1.0 + \left[\frac{(mod_i)}{noise}\right]^2\right] \qquad C = 63.175$$

(g) T-MAX3200 / 135 mm:

$i := 0..36$

$mod_0 := 1$

$mod_1 := .999$

$mod_2 := .994$

$mod_3 := .987$

$mod_4 := .976$

$mod_5 := .963$

$mod_6 := .947$

$mod_7 := .928$

$mod_8 := .907$

$mod_9 := .884$

$mod_{10} := .858$

$mod_{11} := .831$

$mod_{12} := .802$

$mod_{13} := .771$

$mod_{14} := .738$

$mod_{15} := .705$

$mod_{16} := .67$

$mod_{17} := .635$

$mod_{18} := .599$

$mod_{19} := .563$

$mod_{20} := .526$

$mod_{21} := .49$

$mod_{22} := .453$

$mod_{23} := .417$

$mod_{24} := .382$

$mod_{25} := .346$

$mod_{26} := .312$

$mod_{27} := .278$

$mod_{28} := .245$

$mod_{29} := .212$

$mod_{30} := .181$

$mod_{31} := .149$

$mod_{32} := .119$

$mod_{33} := .089$

$mod_{34} := .059$

$mod_{35} := .03$

$mod_{36} := .007$

$noise := .0621$

$$C := \sum_{i=0}^{36} \log\left[1.0 + \left[\frac{(mod_i)}{noise}\right]^2\right] \qquad C = 63.545$$